Bombardier Contribution to AIAA 2nd High-Lift Prediction Workshop

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Advanced Aerodynamics

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Presentation Outline

- Flow solvers: NSU3D and DRAGON
- Grid generation and grid systems
- Case 1 results
  - Solution convergence
  - Grid convergence
  - Surface values
- Case 2 results
  - Effect of slat tracks and flap tracks fairings
  - Reynolds number effect
  - Solver and turbulence model influence
- Conclusion

NSU3D Flow Solver (D. Mavriplis)

- Unstructured Reynolds-averaged Navier-Stokes solver
- "Workhorse" code for high-lift and complex configurations
  - Vertex-based discretization
  - Mixed elements (tetra in far-field, prisms near solid walls)
  - Edge data structure
  - Matrix artificial dissipation
  - Thin-layer assumption in 3 directions with option for full Navier-Stokes terms
  - Turbulence models:
    - Spalart-Allmaras (original formulation)
    - Wilcox k-ω $\Rightarrow$ most computations done with this model
    - SST
  - Agglomeration multigrid

DRAGON Flow Solver

- Bombardier in-house 3D hybrid structured-unstructured RANS solver
  - Cell-centered, coupled solver
- Implicit time integration with LU-SGS approach
  - 1st-order and 2nd-order accurate in time for steady and unsteady simulations, respectively
- 2nd-order accurate Roe's upwind scheme for convective flux and central differencing scheme for viscous flux discretization
  - Venkatakrishnan's limiter to ensure monotonicity
- Spalart-Allmaras turbulence model
  - Standard version, implicit formulation, 2nd-order accurate in space
- Parallel large-scale simulation capability with non-blocking MPI
- Interfaced with CGNS data produced by main-stream commercial grid generators

Grid Generation – ICEM-CFD

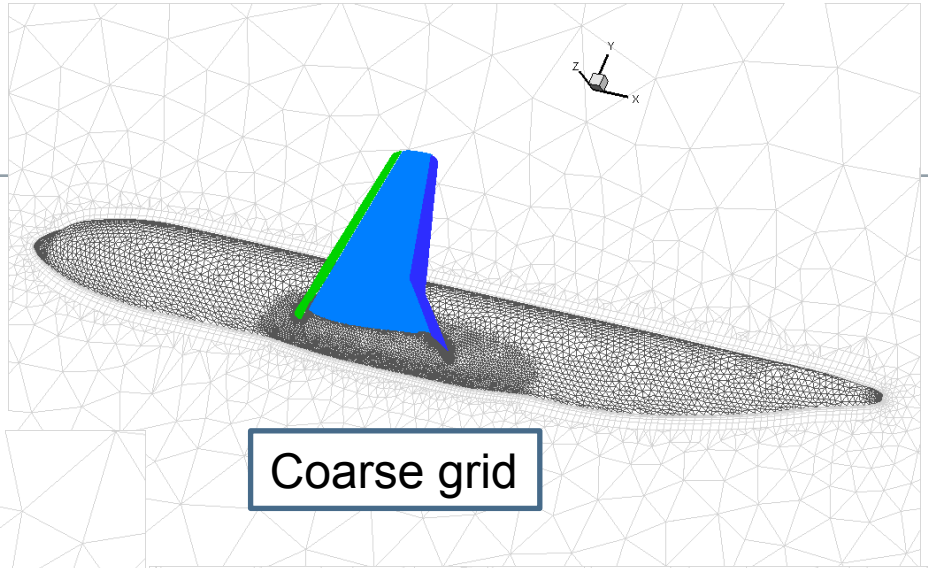
- Tetra module
  - Top-down octree approach
  - Surface grid is a result of volume discretization ⇒ isotropic triangles
  - Nodes projected onto surfaces, specified curves and points
  - Maximum tetra size specified on surfaces and optionally curves
  - Curvature-based refinement
  - Manual repair required
- Prism module
  - Prisms extracted from surface triangles and grown into tetra field
  - Control parameters:
    - Height of 1st cell off the surface
    - Number of layers
    - Non-constant growth ratio, maximum growth ratio
    - Maximum height-to-base ratio ⇒ incomplete layers, pyramids

Grid Systems

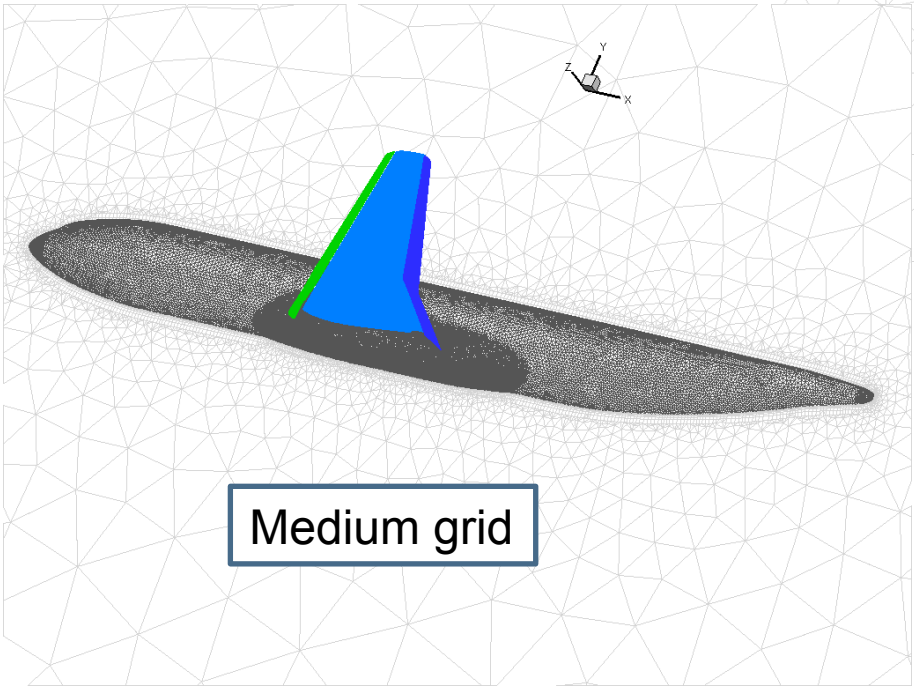
All cases were run on grids generated in-house using ICEM-CFD Tetra/Prism

	Case 1 Coarse Grid	Case 1 Medium Grid	Case 1 Fine Grid	Case 2 Medium Grid
Number of nodes	17 477 000	43 859 000	121 407 000	49 018 000
Number of tetra	10 083 000	25 542 000	85 987 000	28 356 000
Number of prisms	30 953 000	77 016 000	208 056 000	86 120 000
1st cell height	0.000 55	0.000 35	0.000 24	0.000 35
Growth ratio	1.085 – 1.8	1.085 – 1.8	1.085 – 1.8	1.085 – 1.8
Max prism height-to-base ratio	1.8	1.8	1.8	1.8

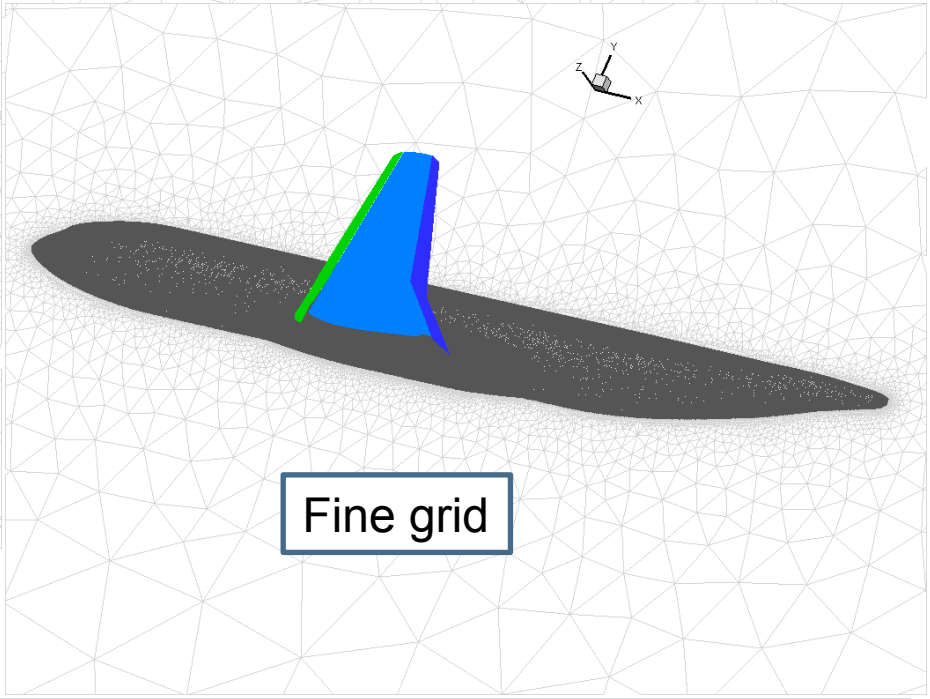
Case 1 – Grid Systems



Coarse grid

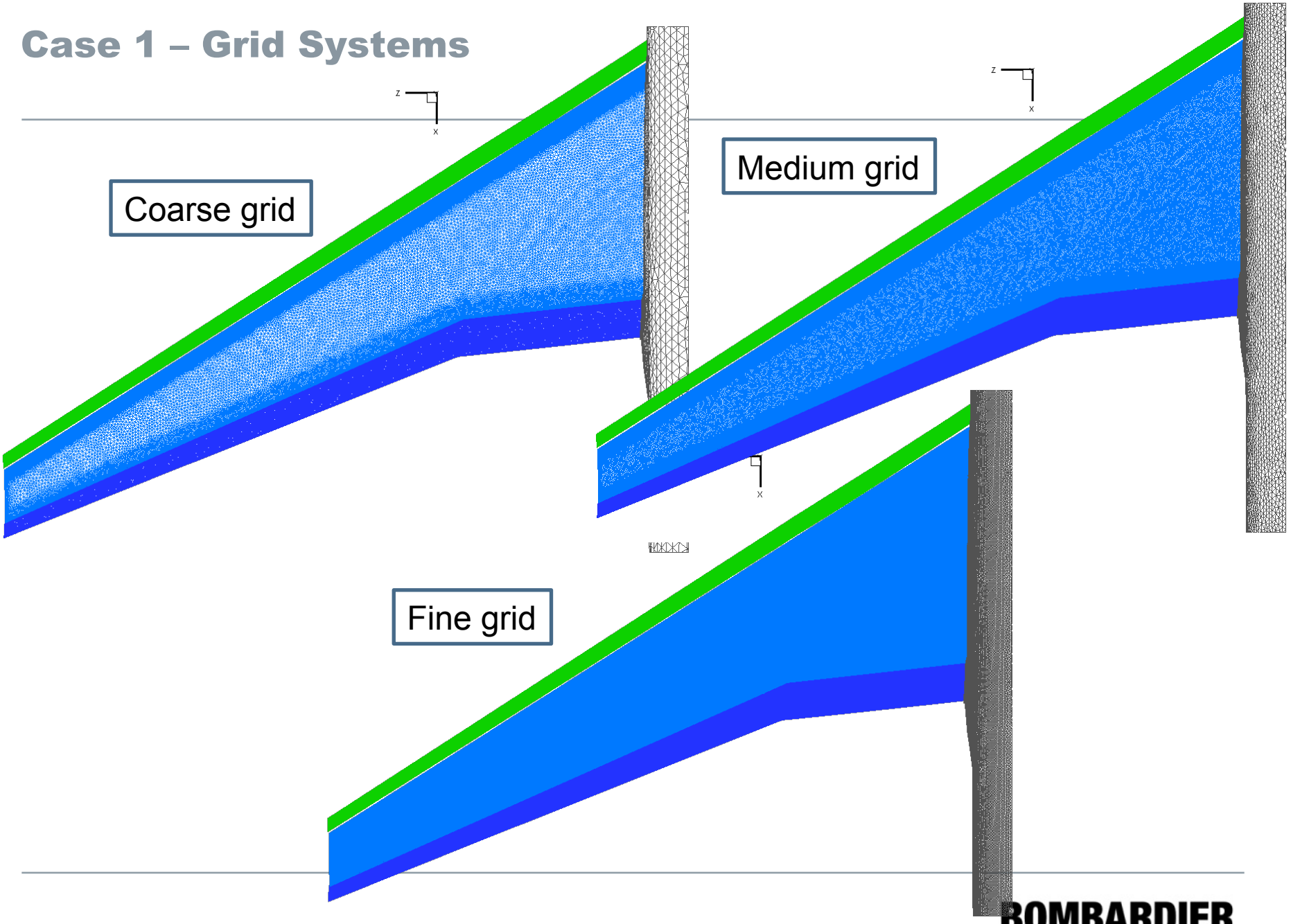


Medium grid



Fine grid

Case 1 – Grid Systems



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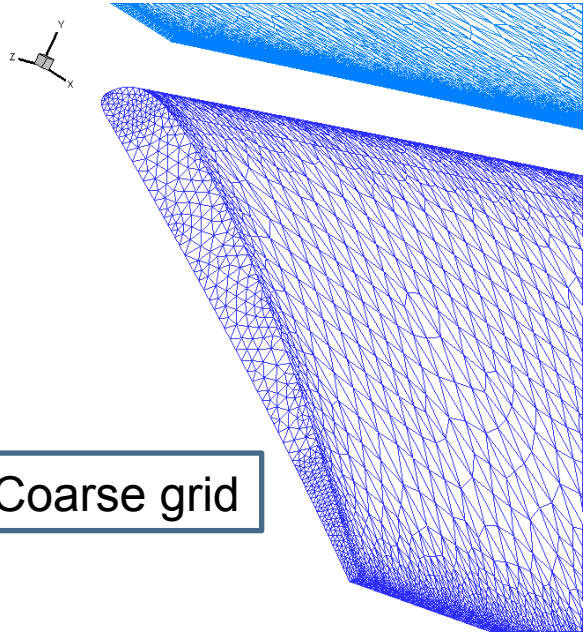
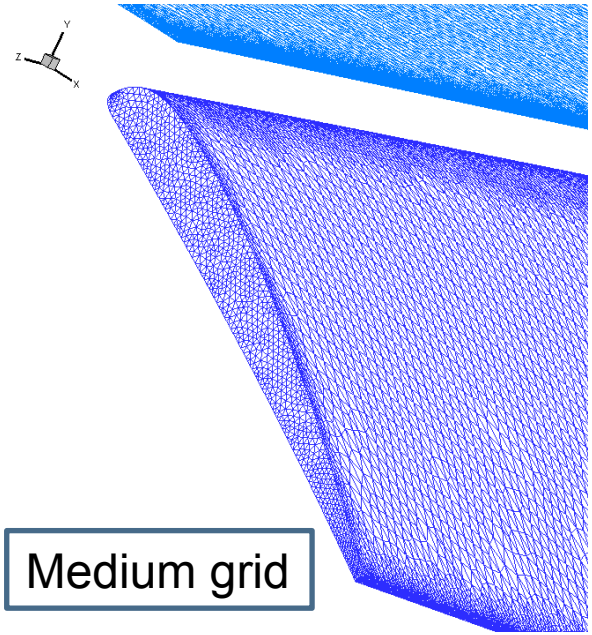
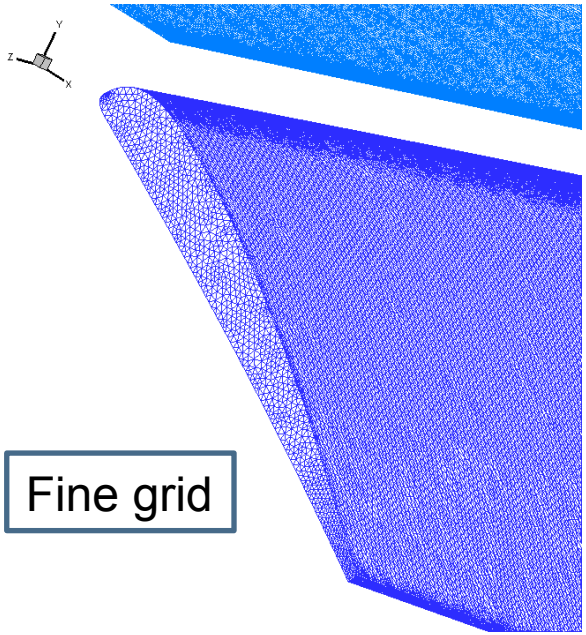
Case 1 – Grid Systems



Coarse grid



Medium grid



Fine grid

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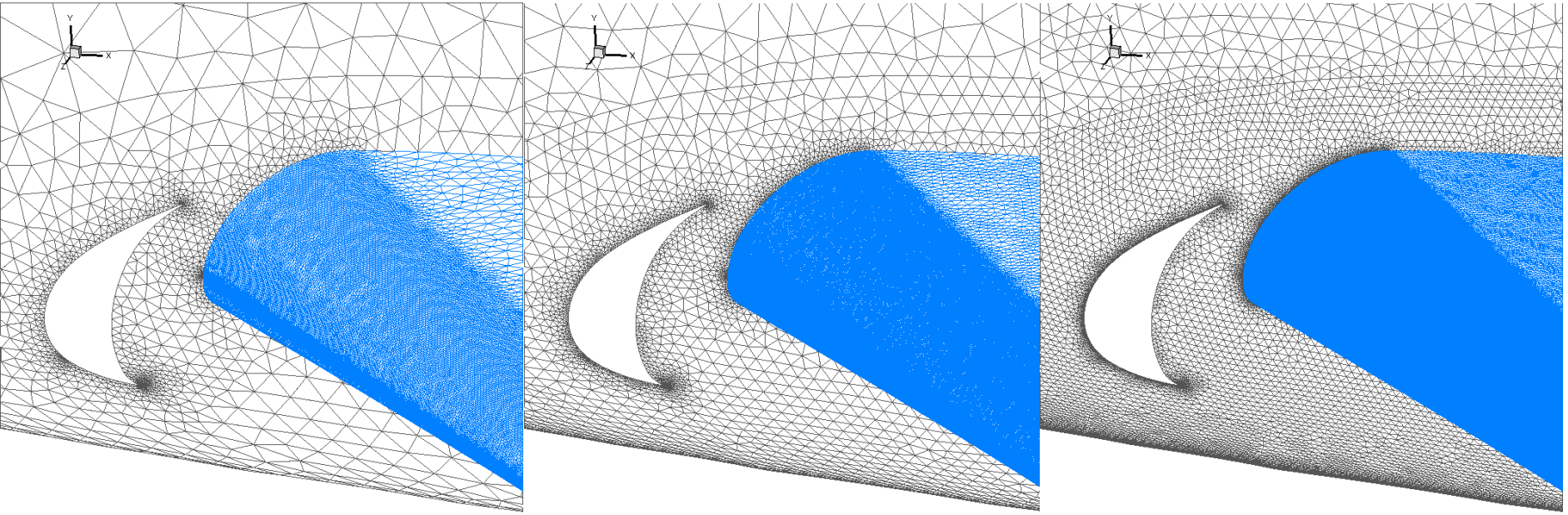

Coarse grid

Medium grid

Fine grid

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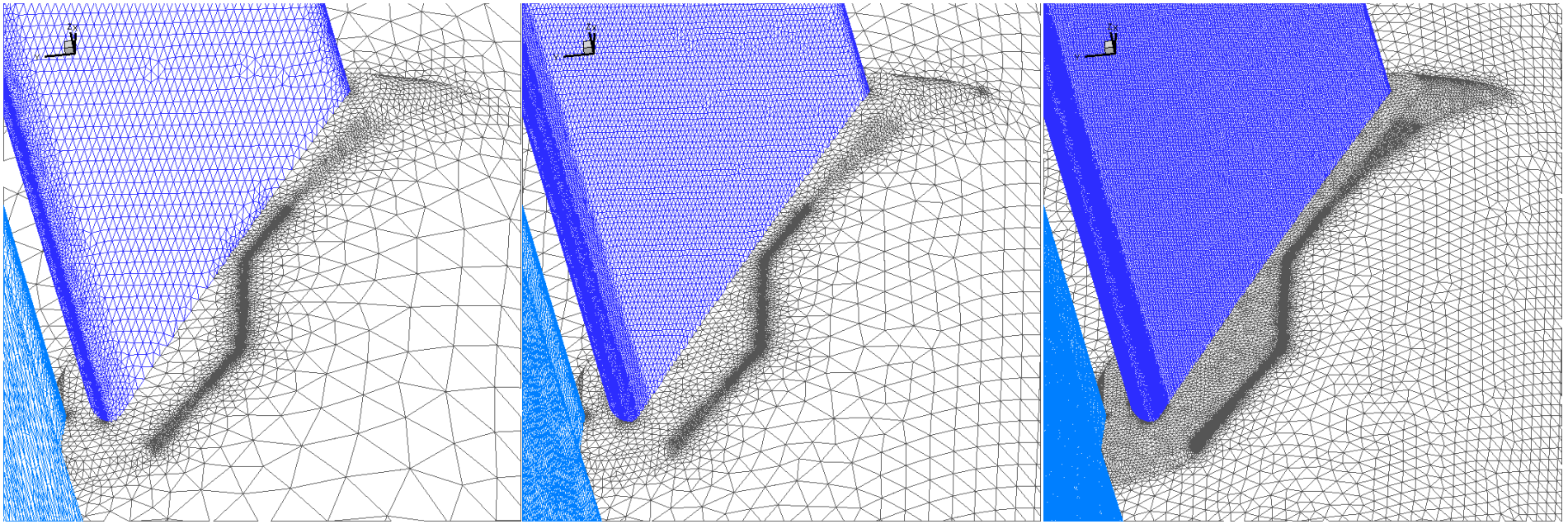

Coarse grid

Medium grid

Fine grid

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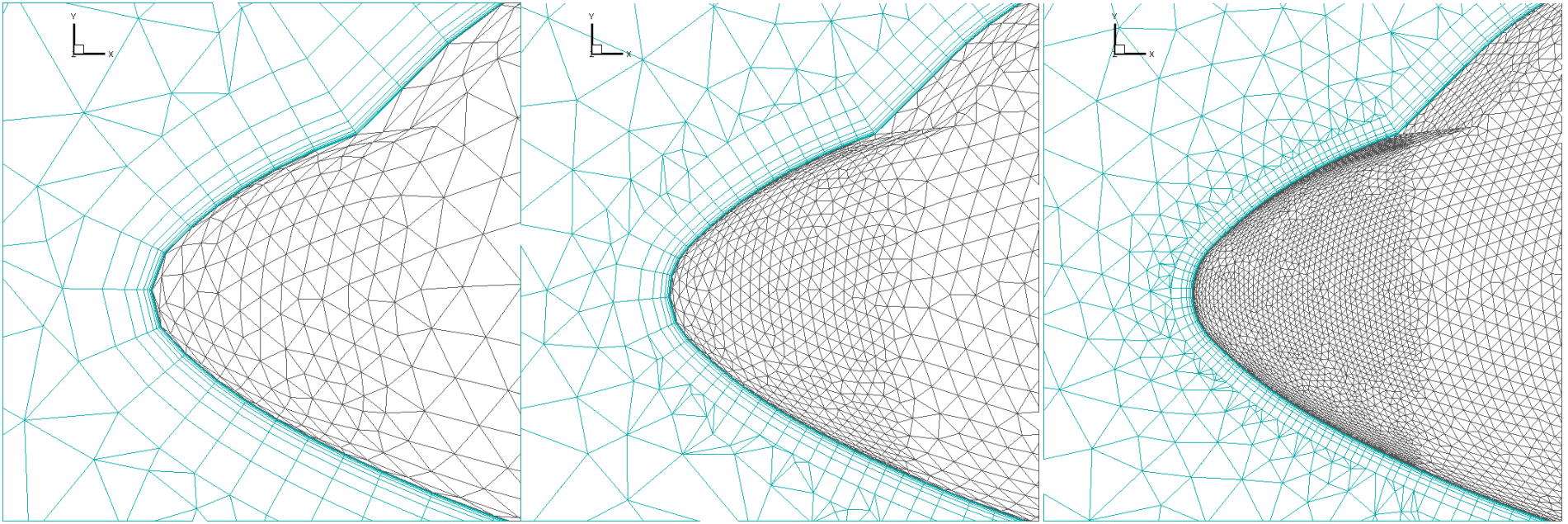
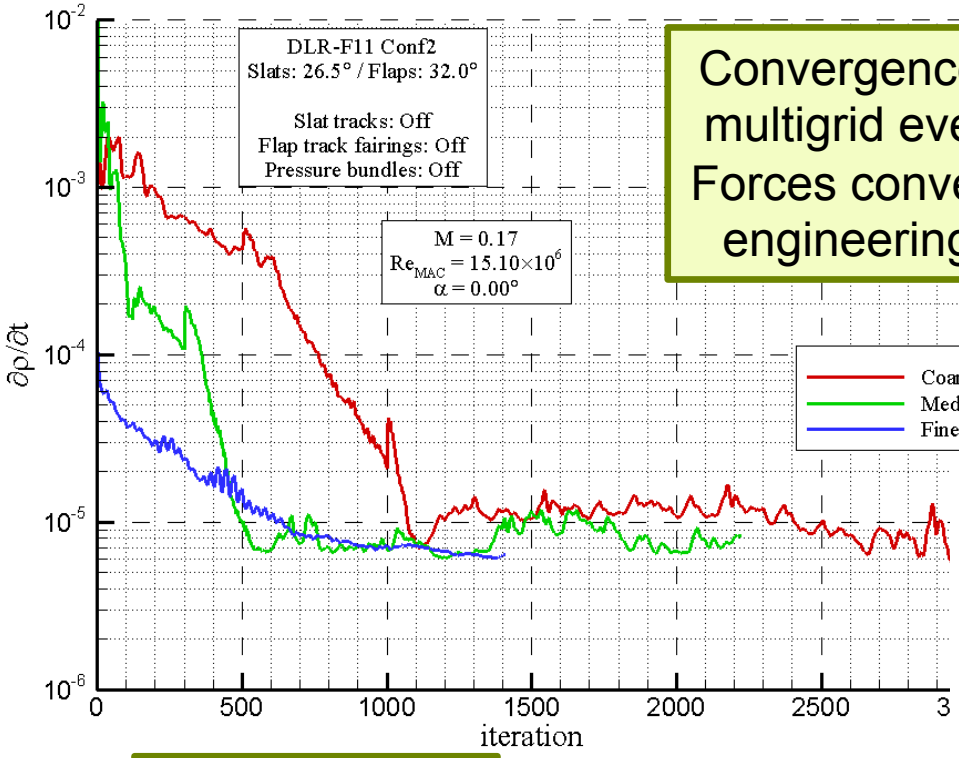


Coarse grid

Medium grid

Fine grid

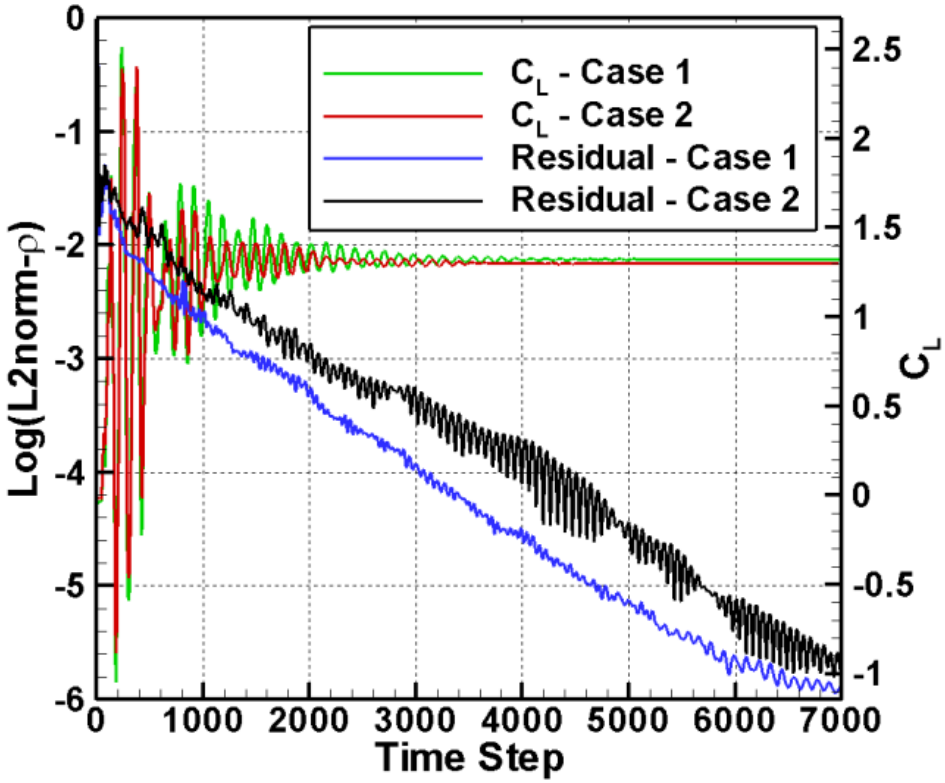
Case 1 – Grid Study - Residual Convergence



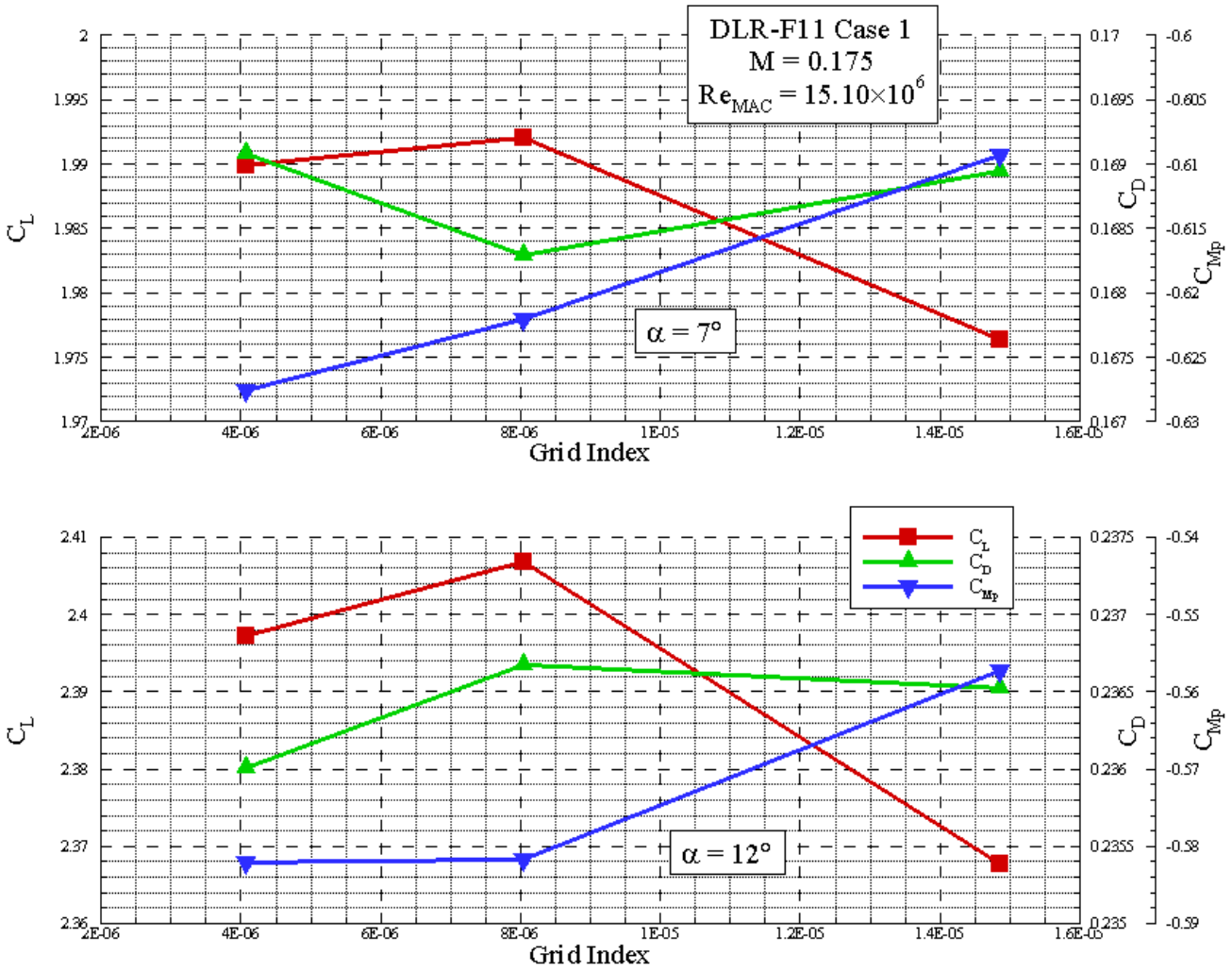
Convergence stalled on multigrid even at α = 0°
Forces converged within engineering accuracy

NSU3D – k-ω

DRAGON – S-A
Single grid
Medium grid



Case 1 – Grid Convergence



Something wrong with fine grid ?

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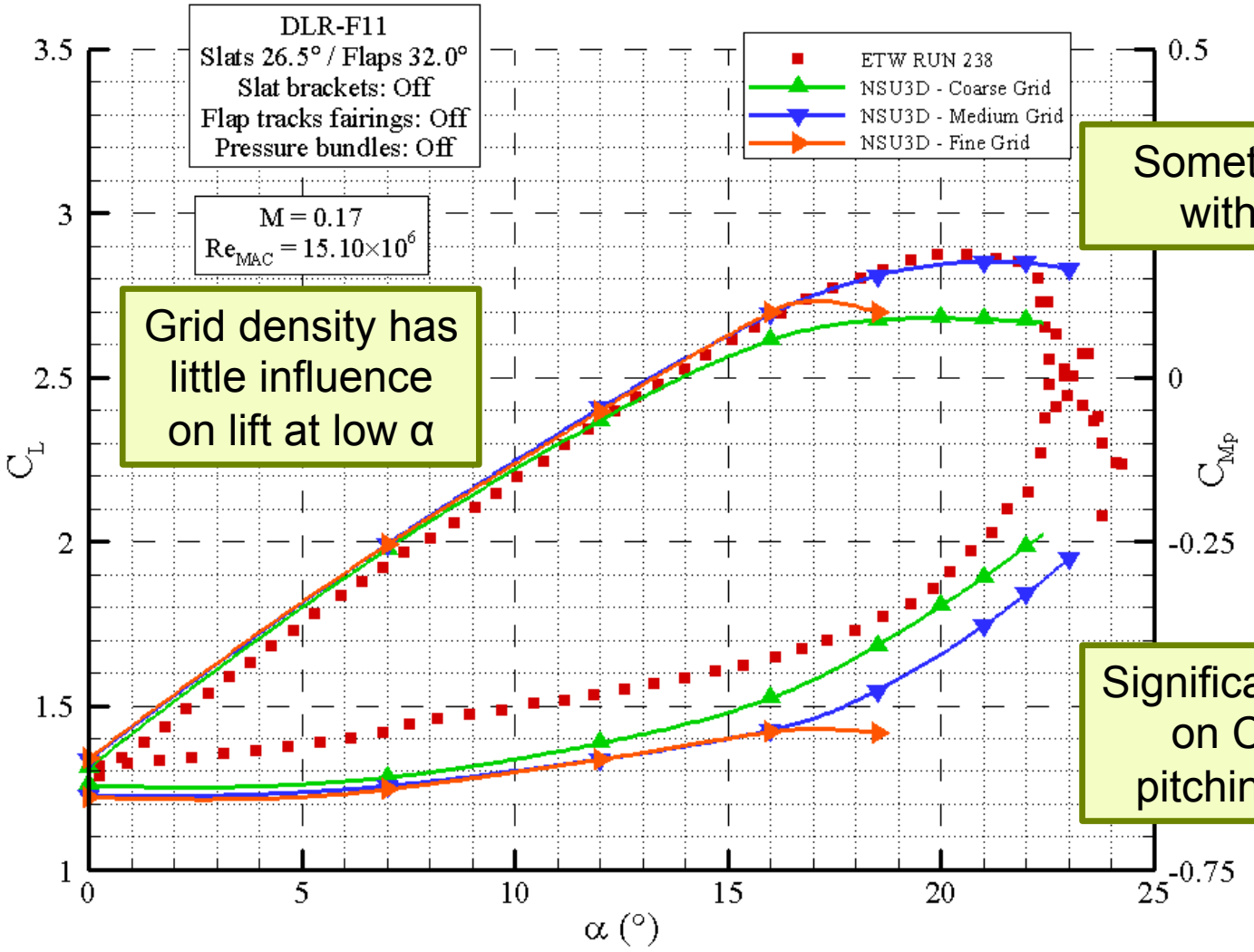
Case 1 - Grid Study – Lift and Pitching Moment



Grid density has little influence on lift at low α

Something wrong with fine grid

Significant influence on C_{Lmax} and pitching moment

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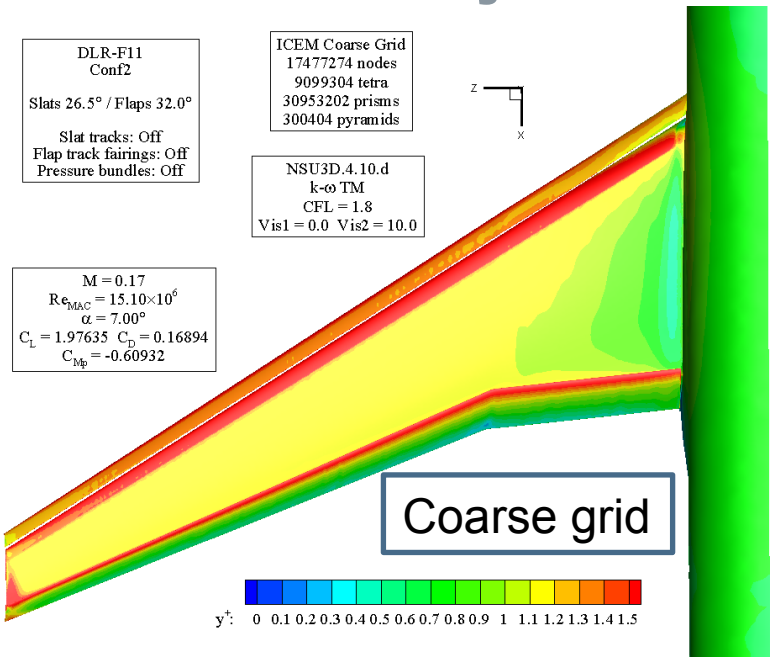
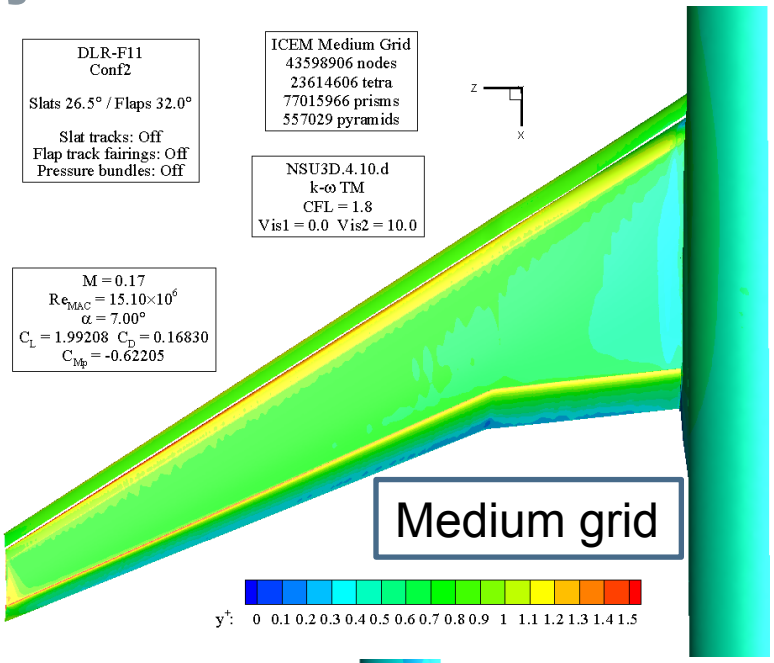
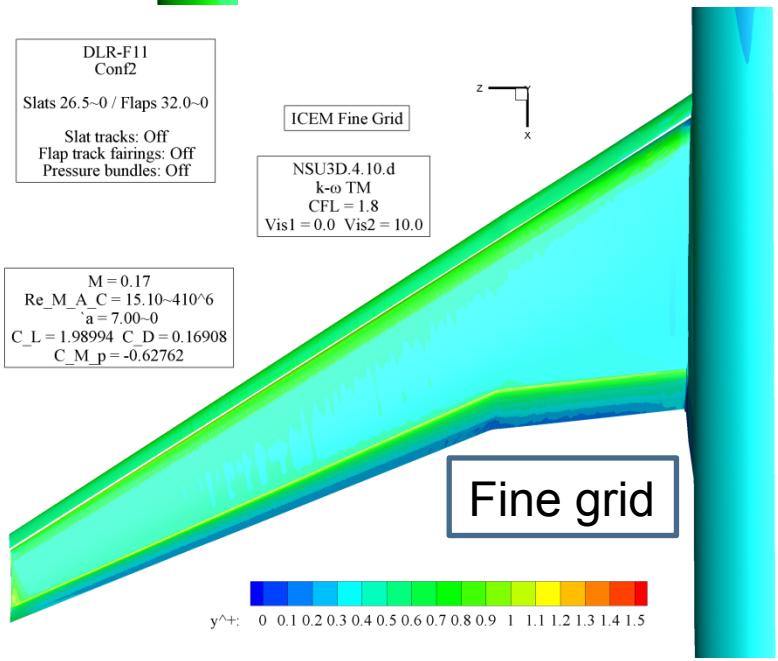
Case 1 – Grid Study – Near-Wall y^+ Values





α = 7°



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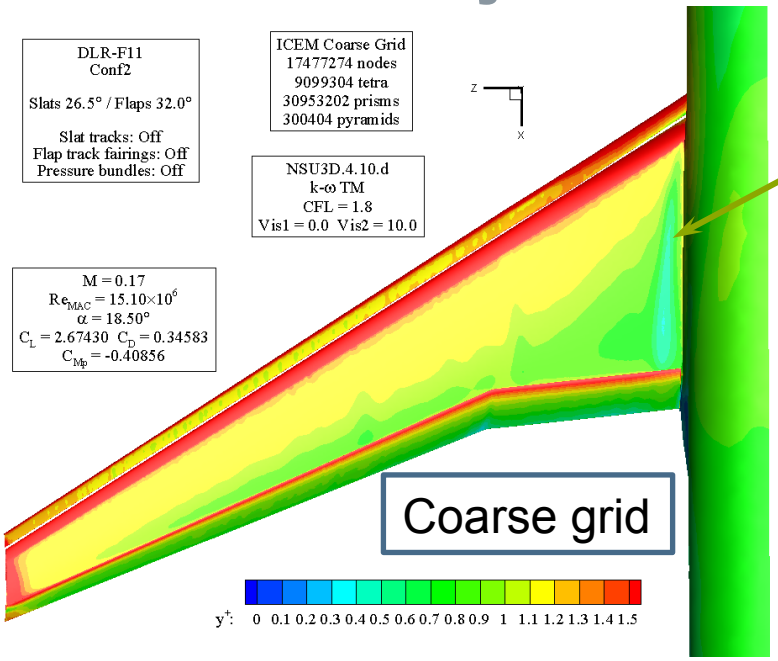
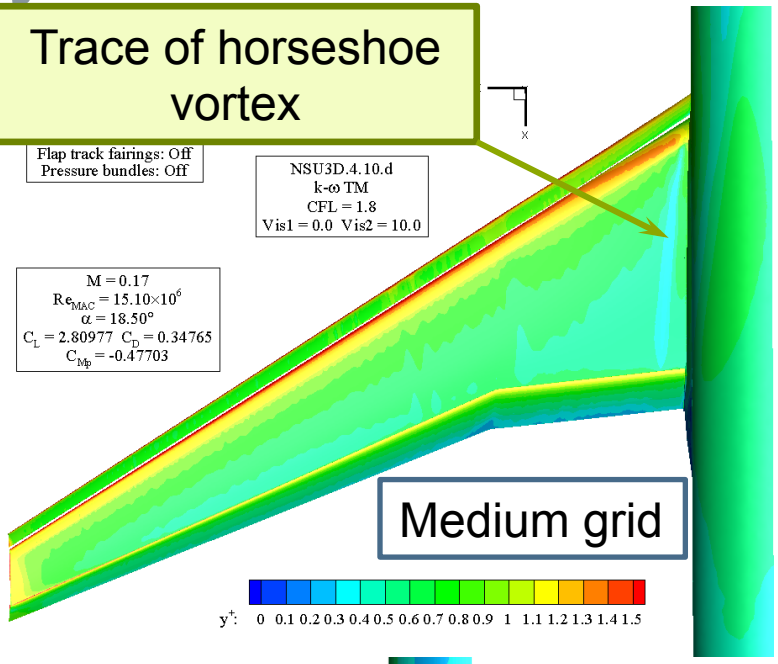
Case 1 – Grid Study – Near-Wall y^+ Values



Coarse grid

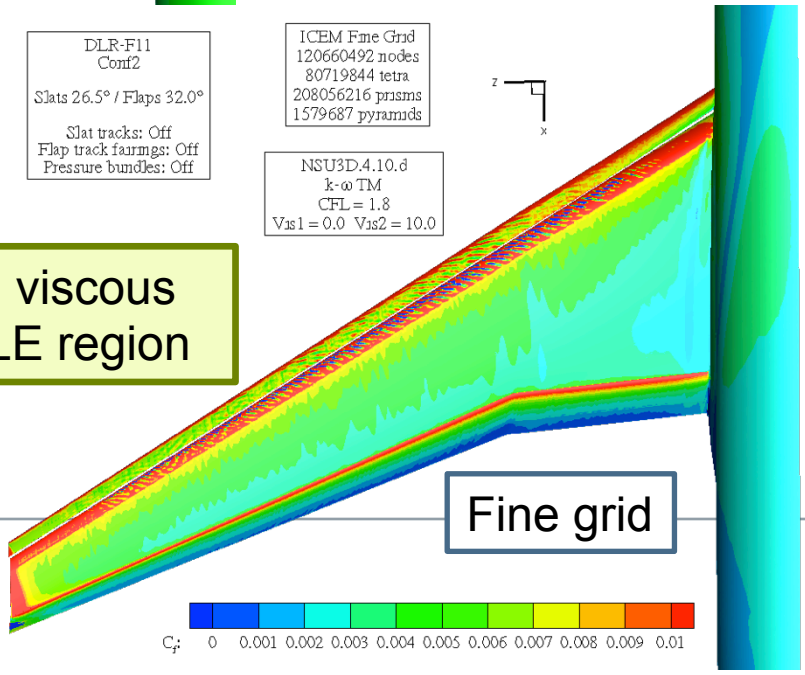
Trace of horseshoe vortex



Medium grid

α = 18.5°

Potential cause: viscous layer too thin in LE region



Fine grid

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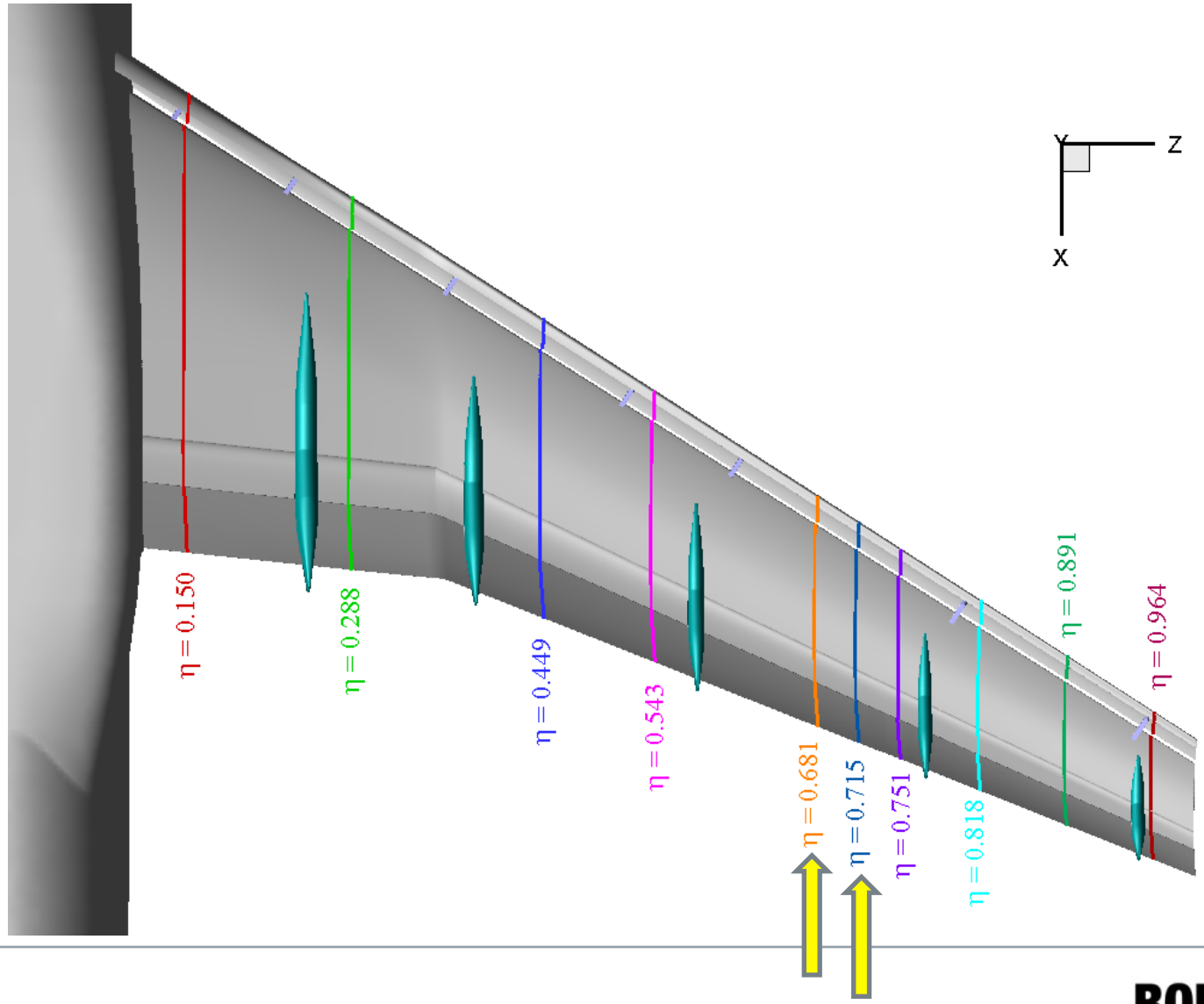
Case 1 - Grid Study – Surface Pressure Distributions



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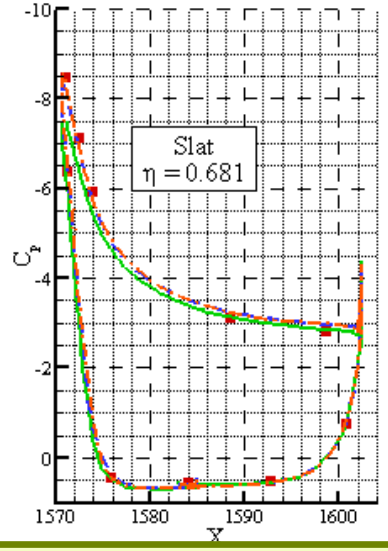
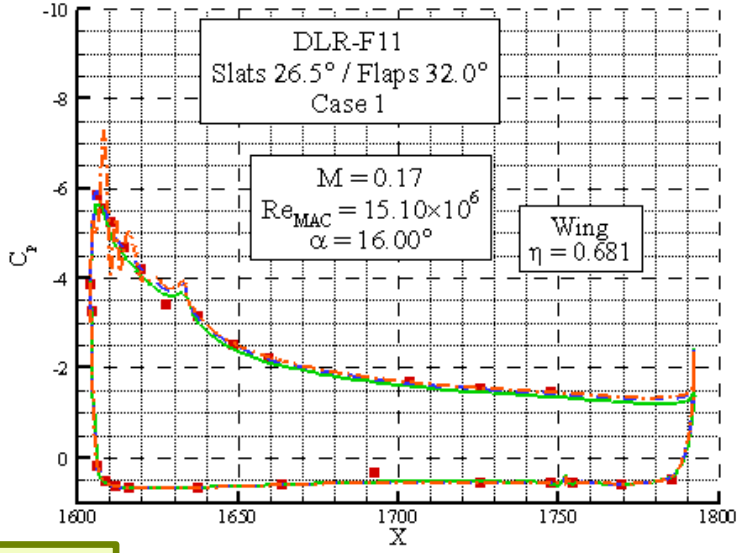
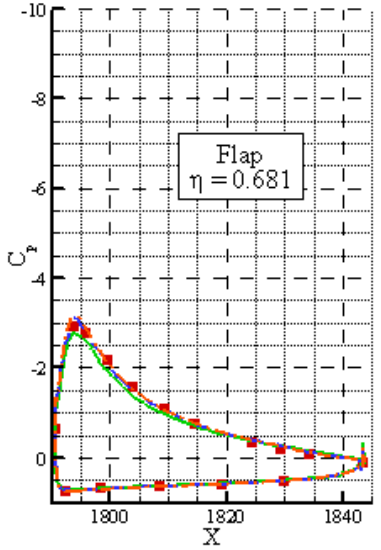
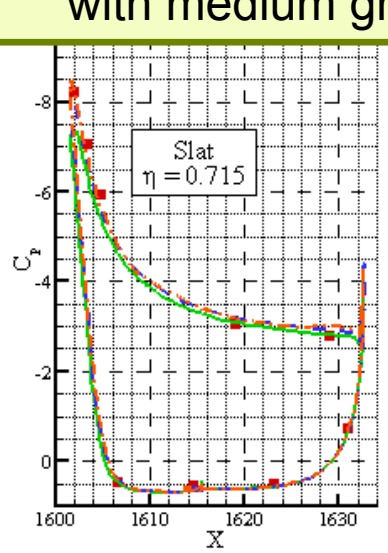
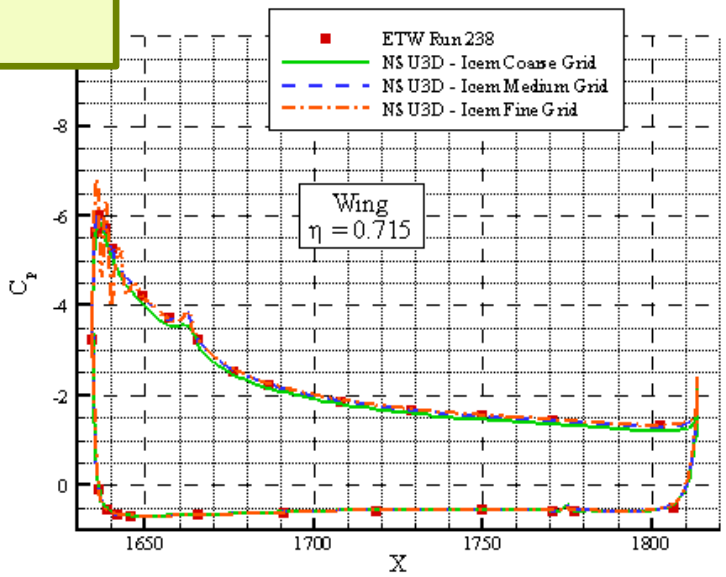


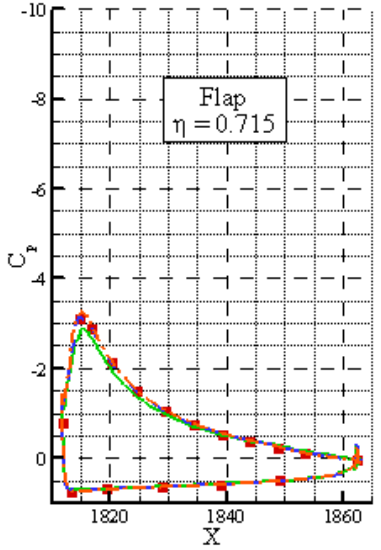




Prediction of peaks improved with medium grid







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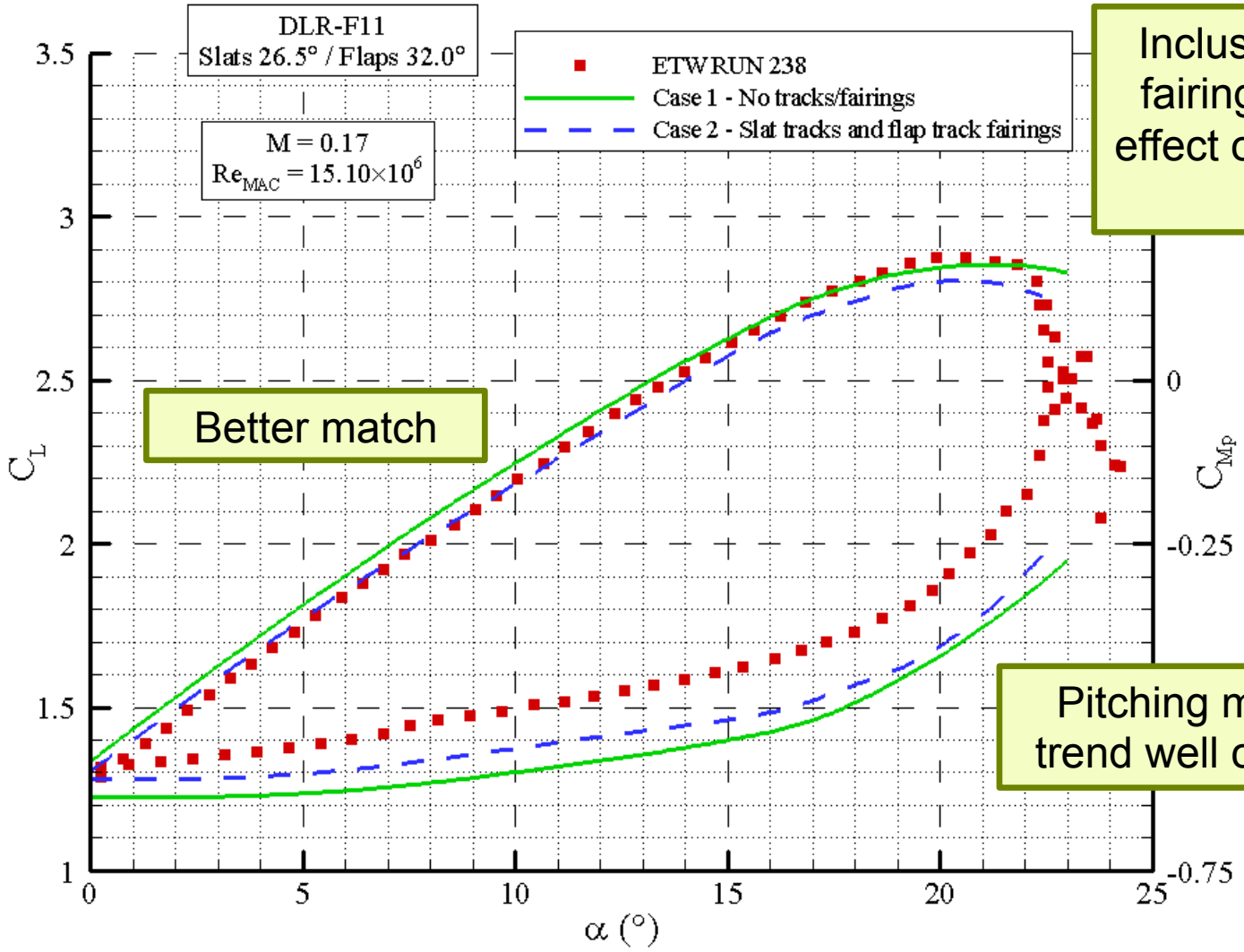
Case 2 - Slat Tracks and Flap Tracks Fairings
Lift and Pitching Moment



Inclusion of tracks and fairings has significant effect on lift and pitching moment

Better match

Pitching moment trend well captured

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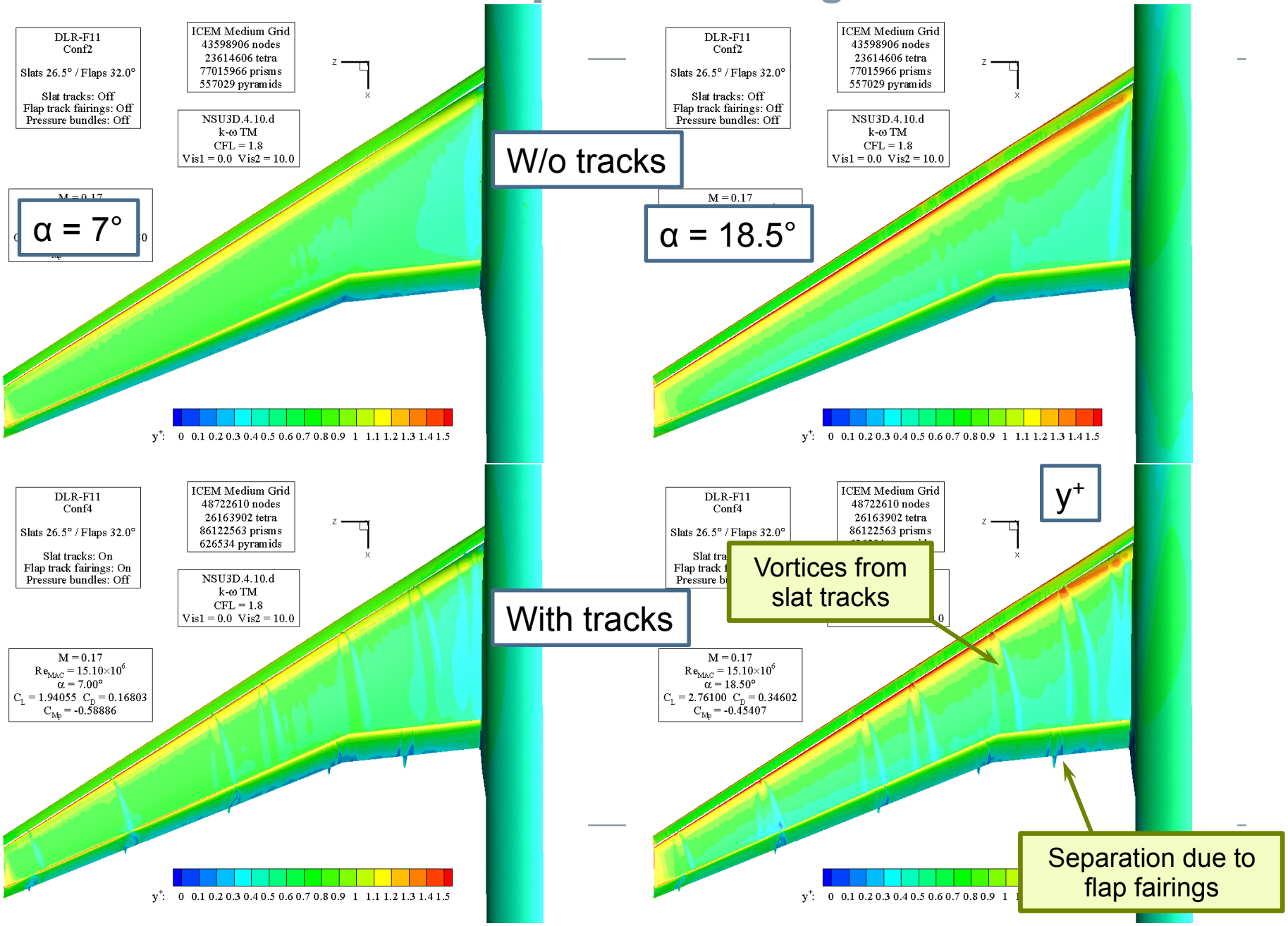
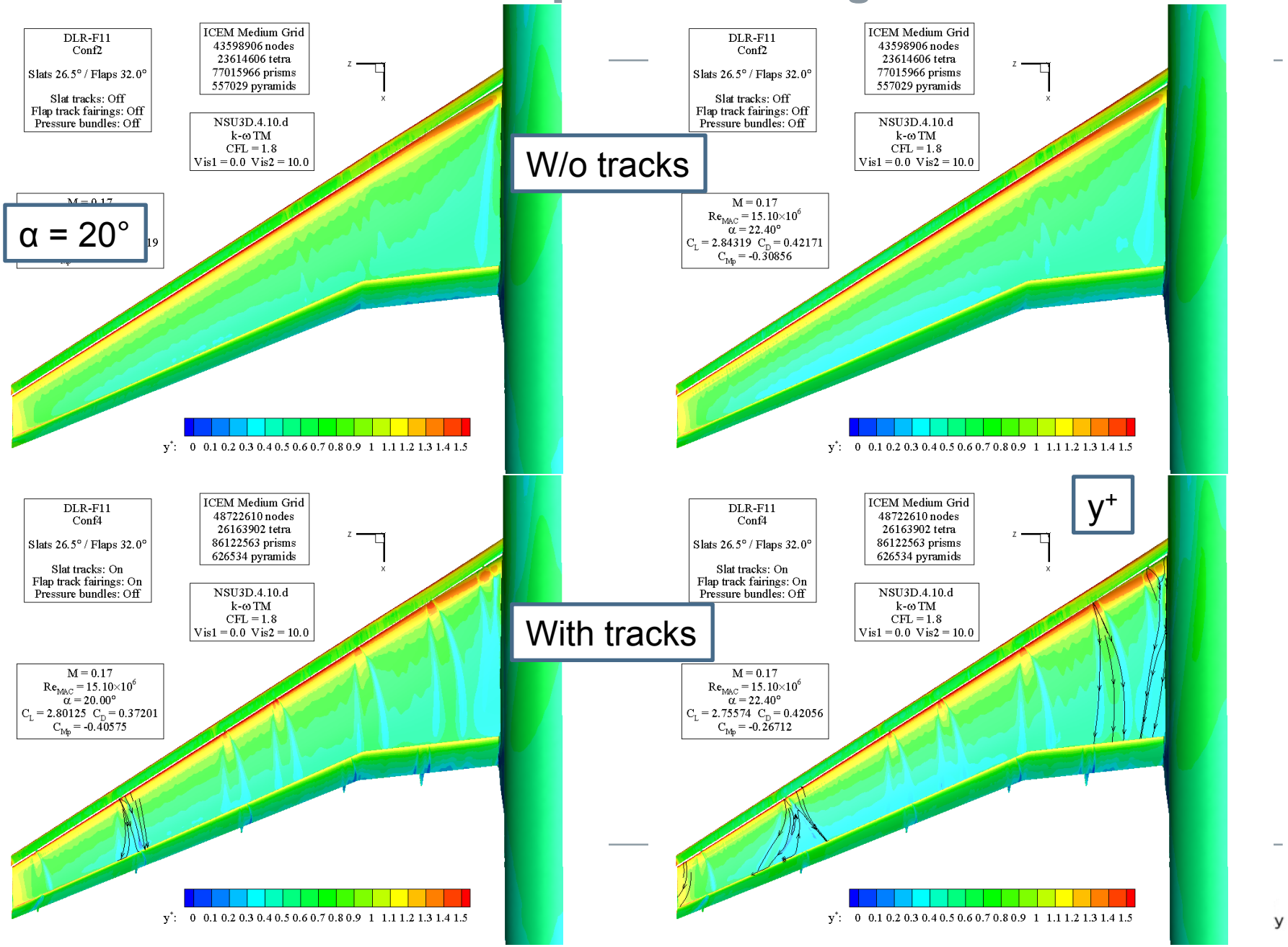
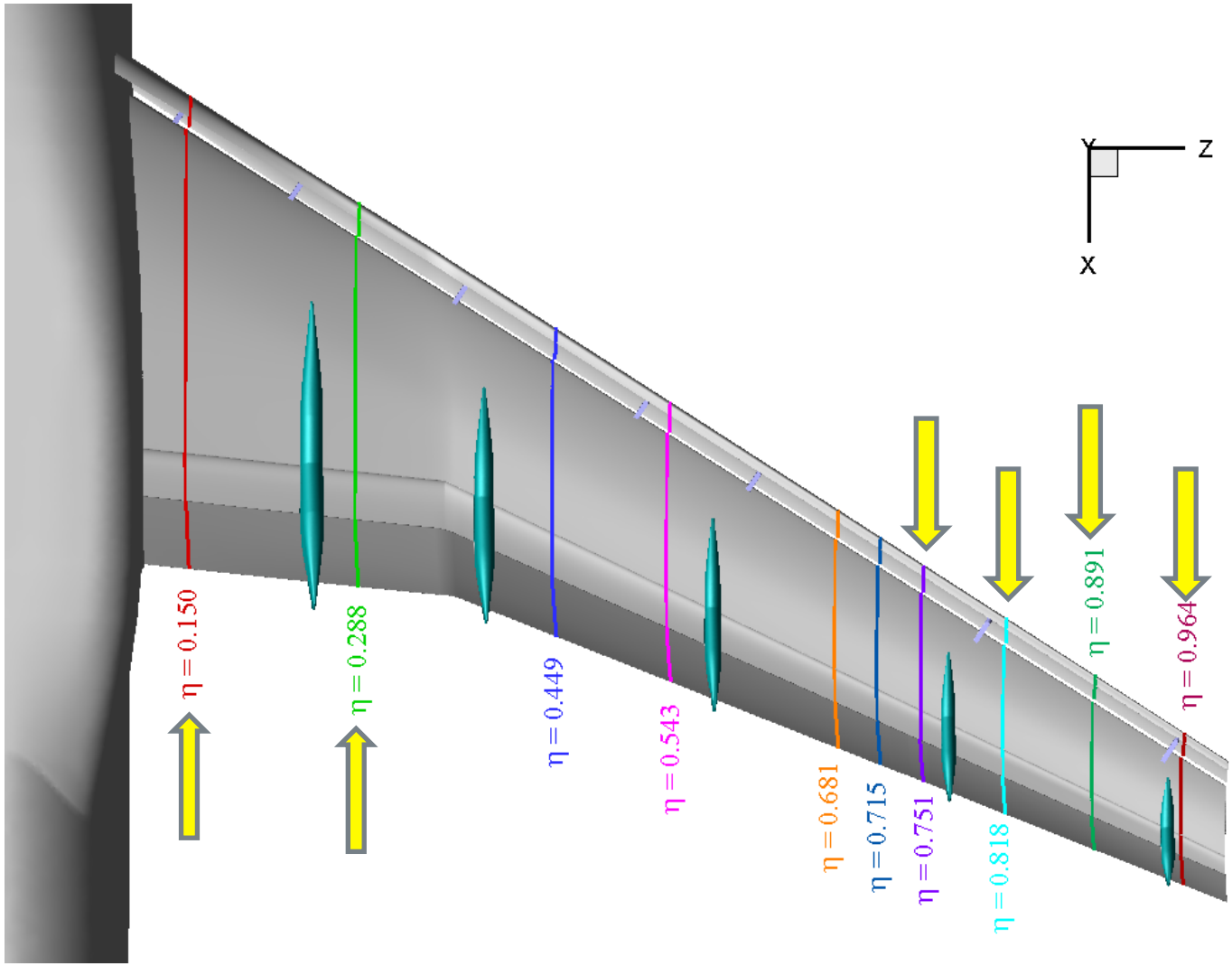
Case 2 - Slat tracks and flap tracks fairings – Near-wall Values



Case 2 - Slat tracks and flap tracks fairings – Near-wall Values



Case 2 - Slat Tracks and Flap Tracks Fairings
Surface Pressure Distributions



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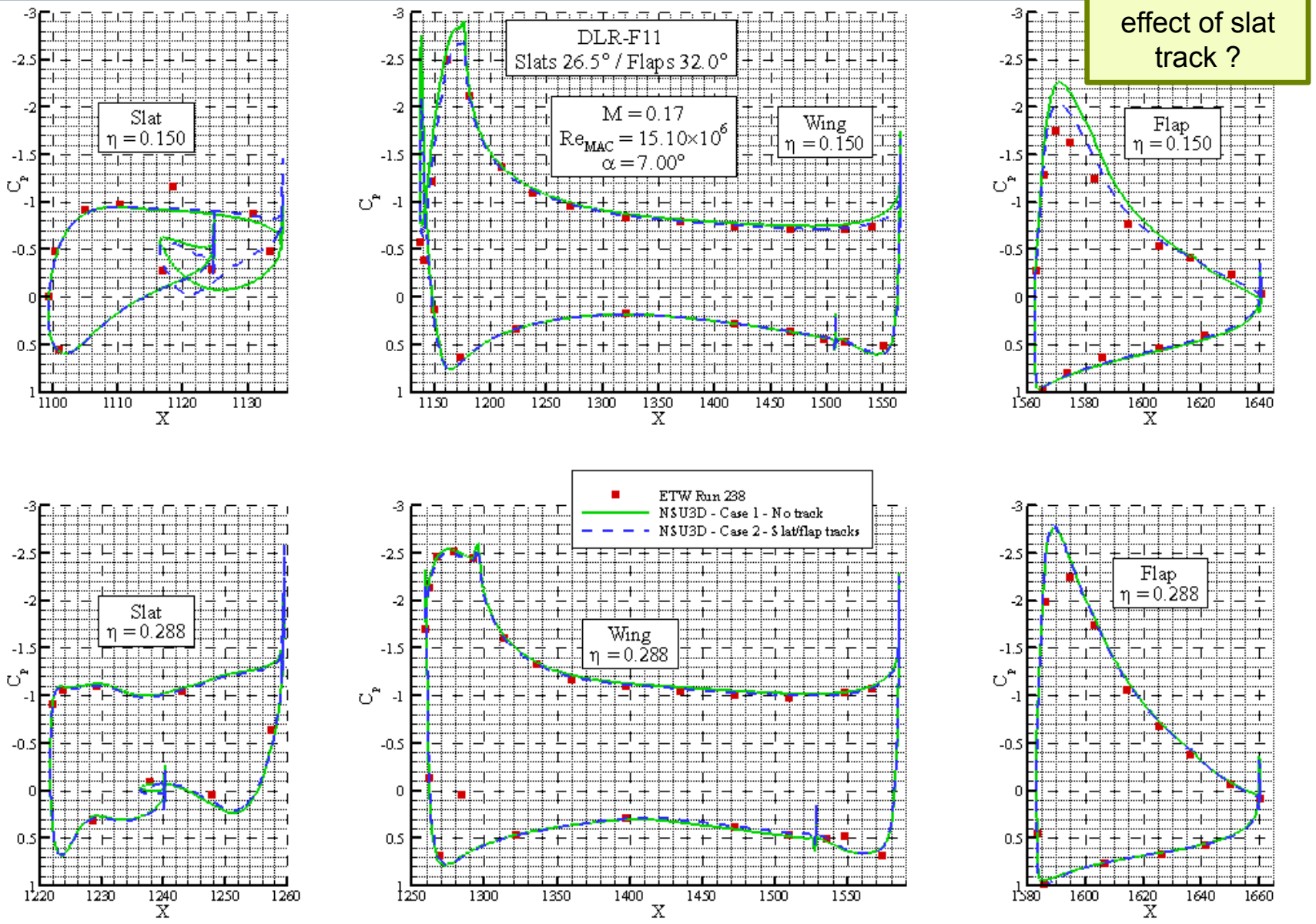
Case 2 - Slat Tracks and Flap Tracks Fairings
Surface Pressure Distributions

Downstream effect of slat track ?



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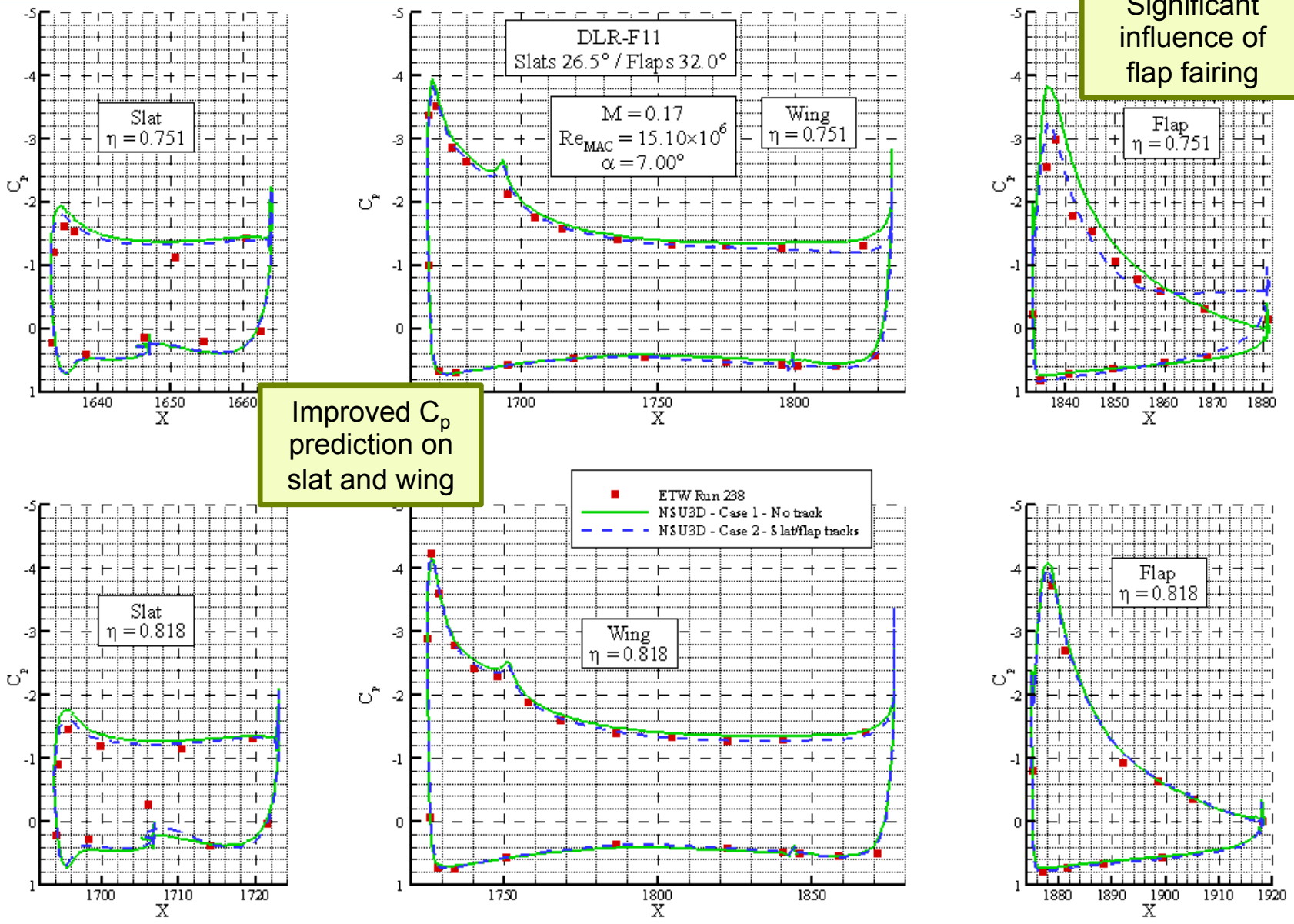
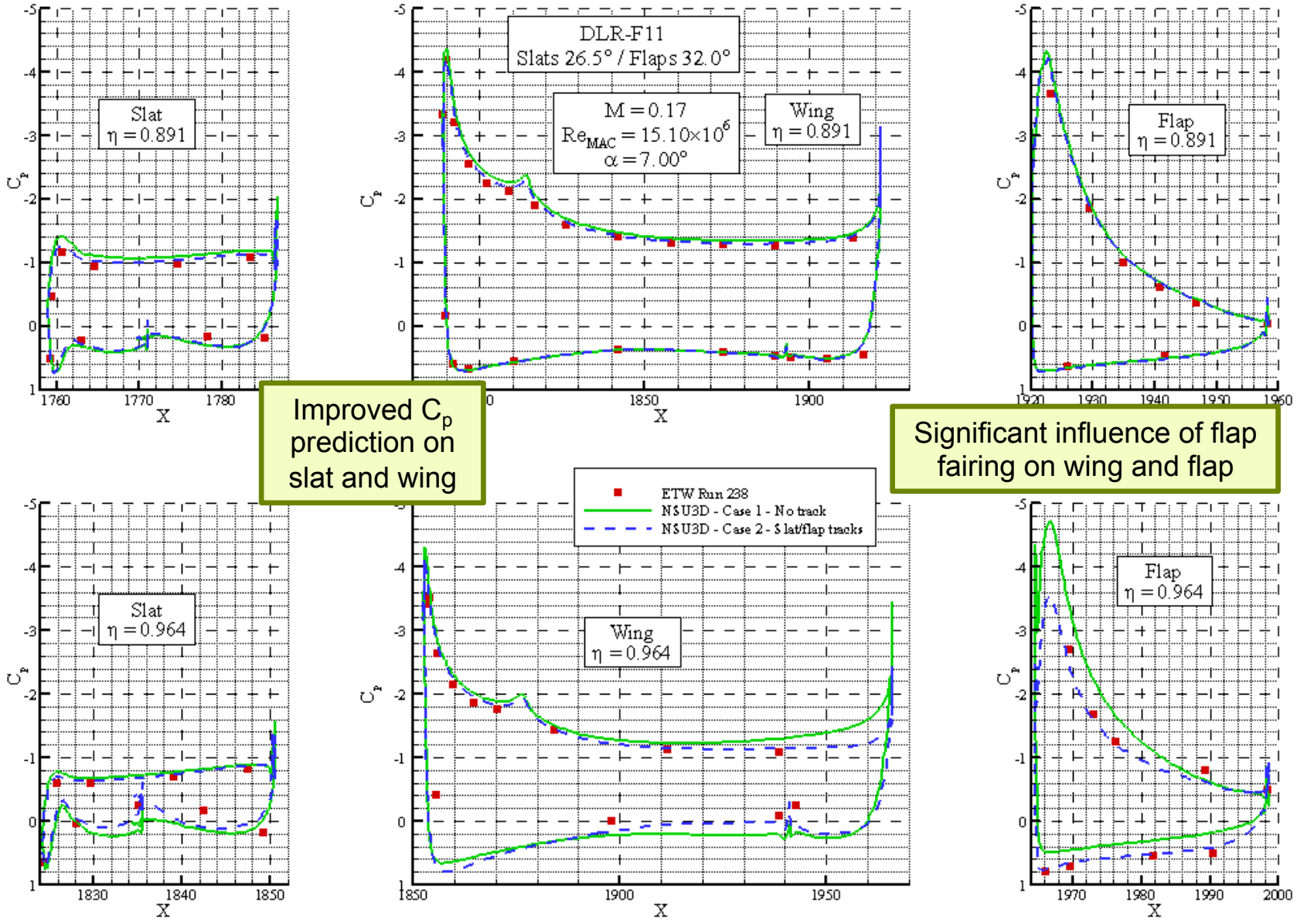


Significant influence of flap fairing

Improved C_p prediction on slat and wing

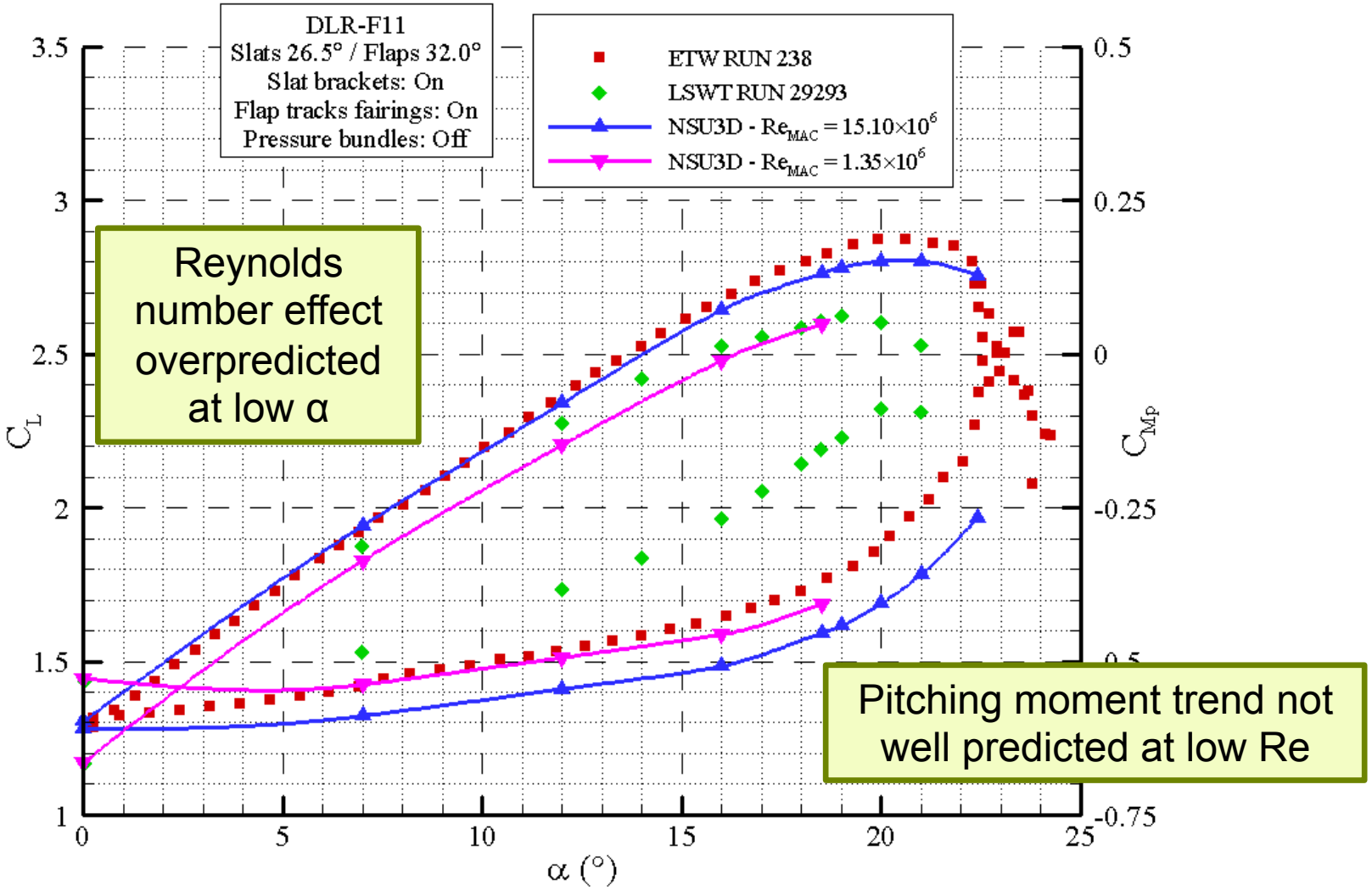
Case 2 - Slat Tracks and Flap Tracks Fairings
Surface Pressure Distributions



Improved C_p prediction on slat and wing

Significant influence of flap fairing on wing and flap

Case 2 – Reynolds Number Effect
Lift and Pitching Moment



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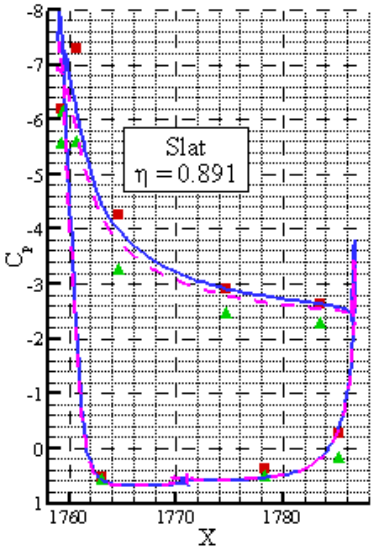
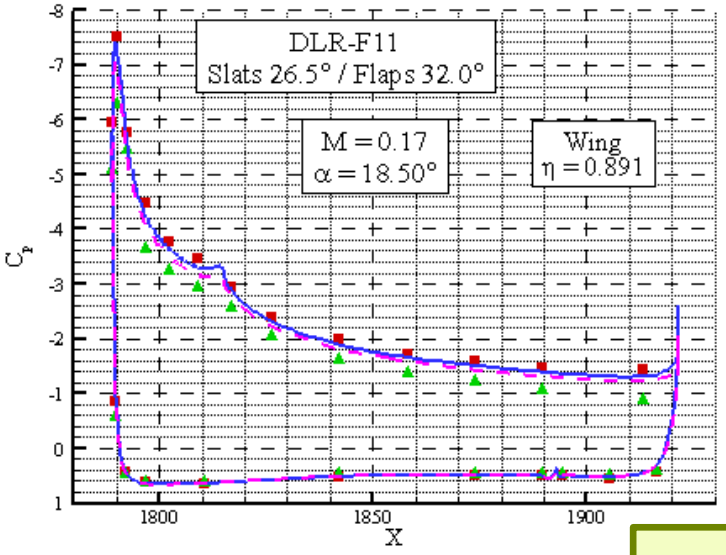
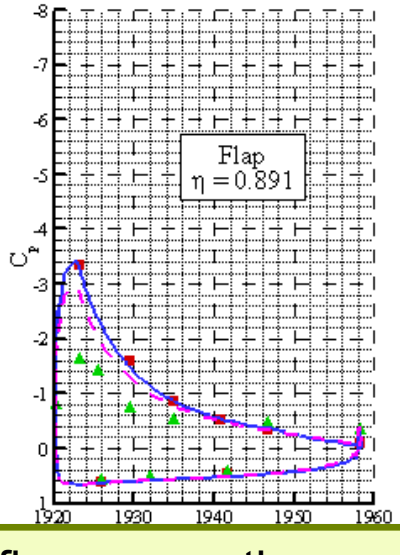
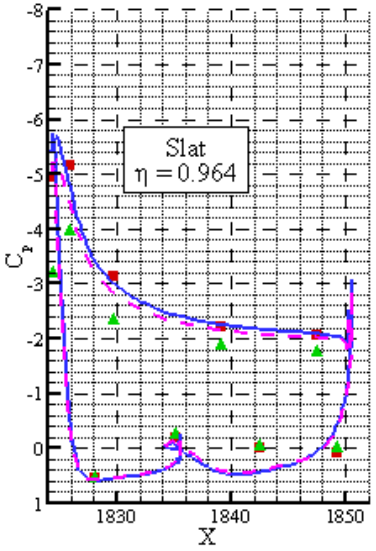
Case 2 – Reynolds Number
Surface Pressure Distributions

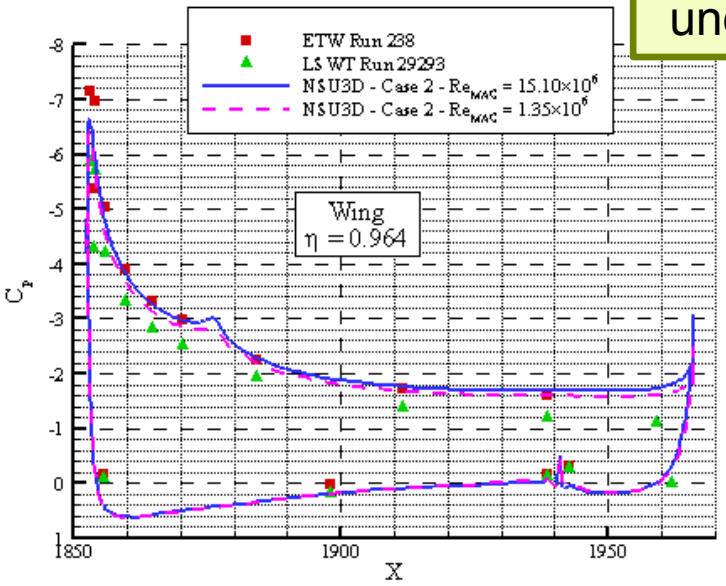


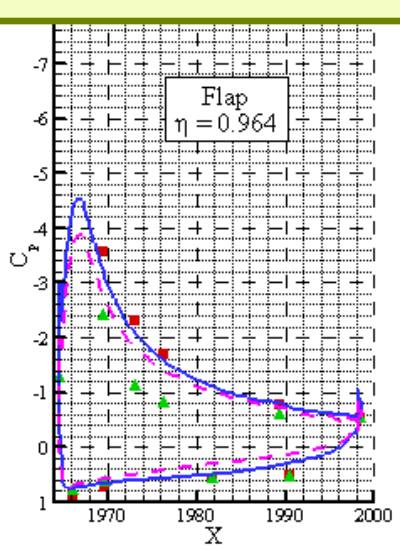




OB flow separation underpredicted at low Re

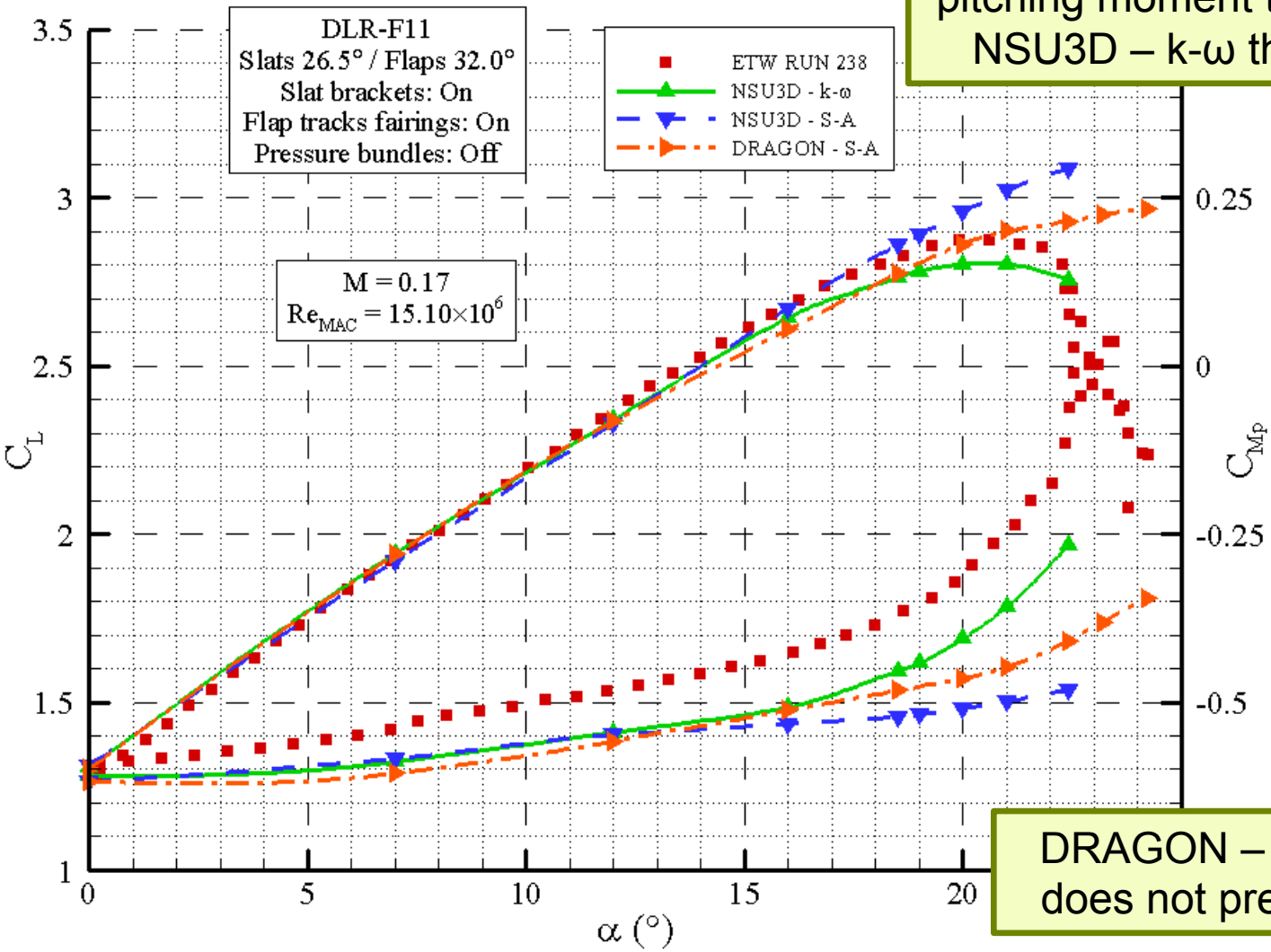






Case 2 – Solver and Turbulence Model
Lift and Pitching Moment

Better prediction of α_{stall} and pitching moment trend with NSU3D – k-ω than S-A



DRAGON – S-A also does not predict stall

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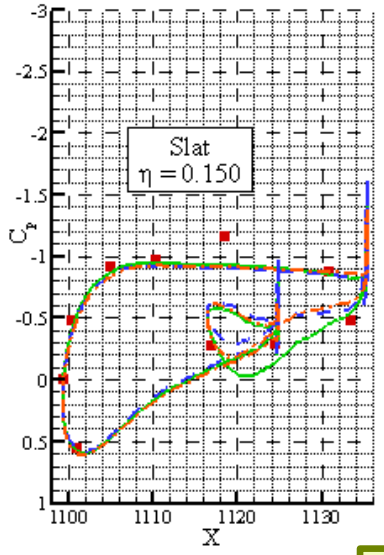
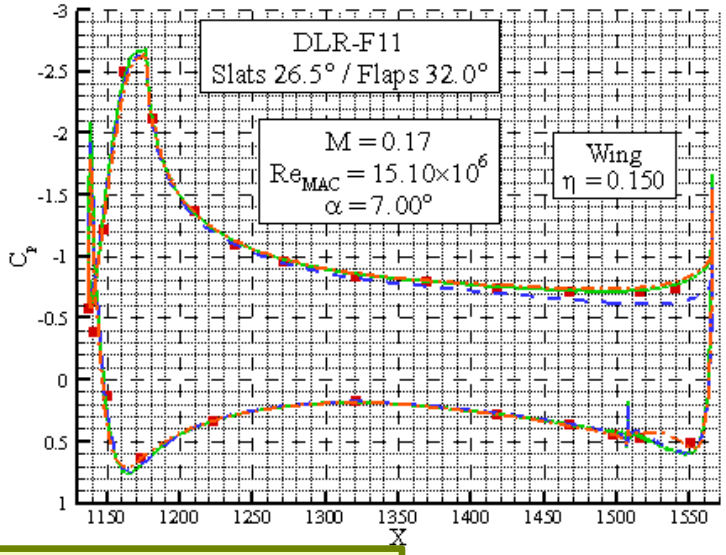
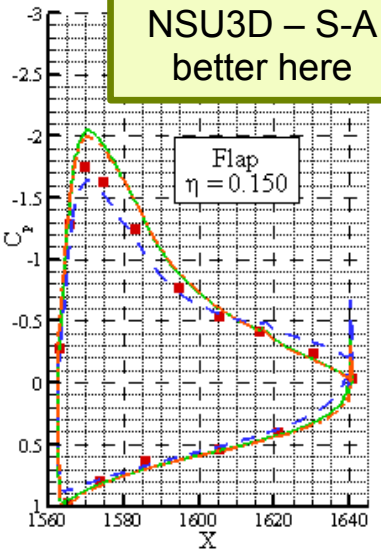
Case 2 – Solver and Turbulence Model
Surface Pressure Distributions

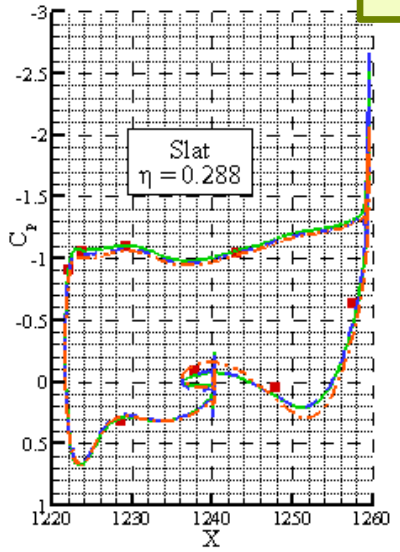


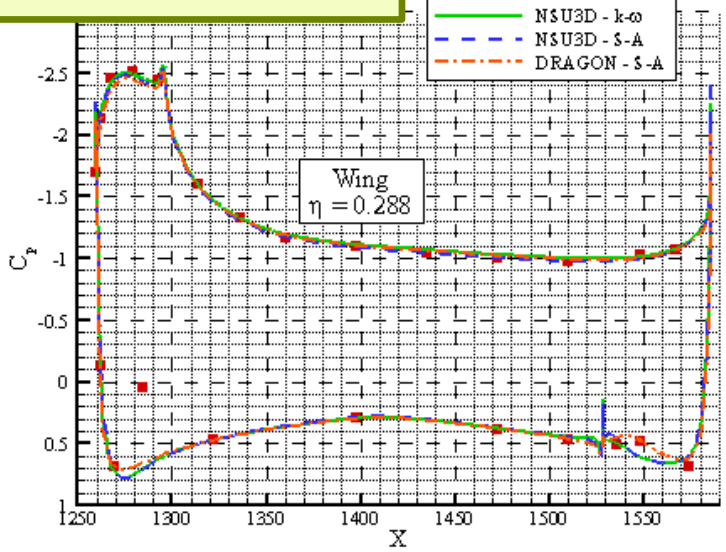


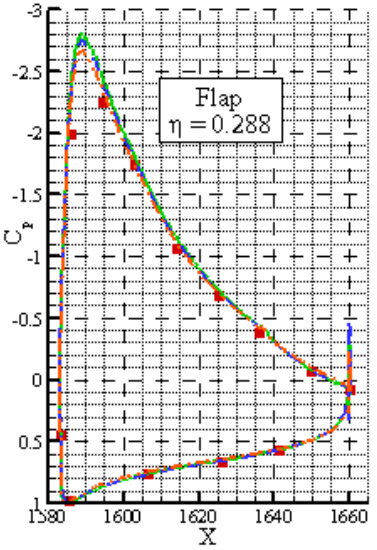


NSU3D – S-A better here

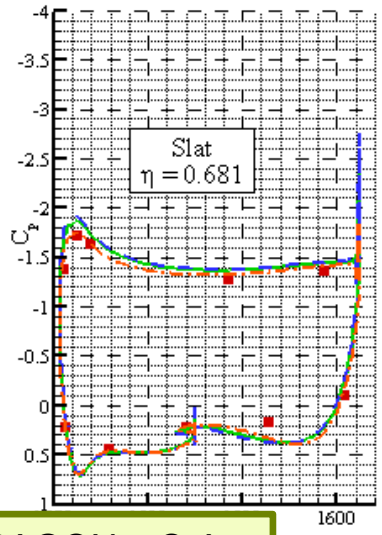
DRAGON – S-A similar to NSU3D – k-ω

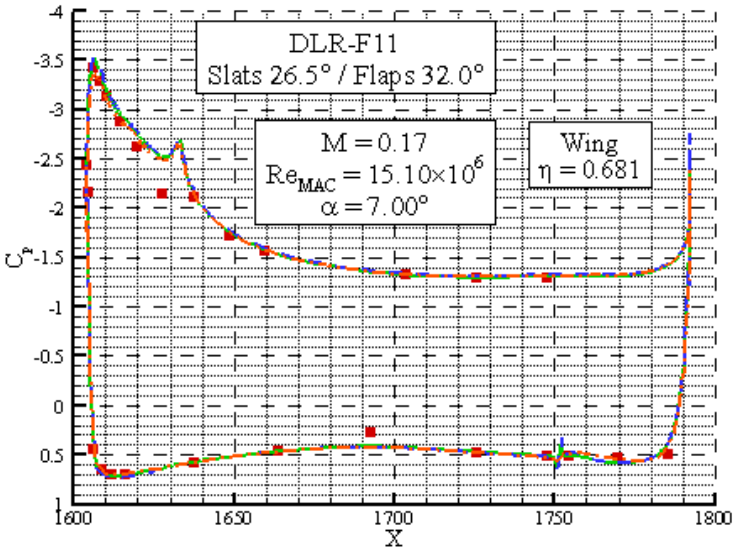


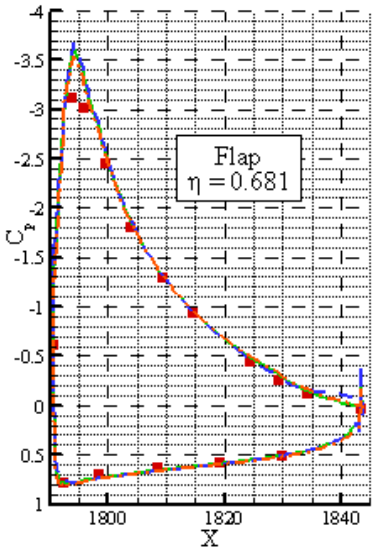




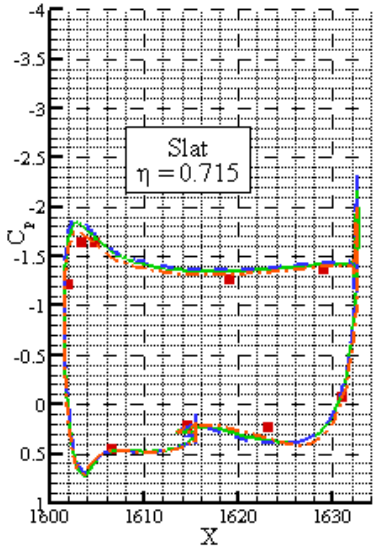
Case 2 – Solver and Turbulence Model
Surface Pressure Distributions

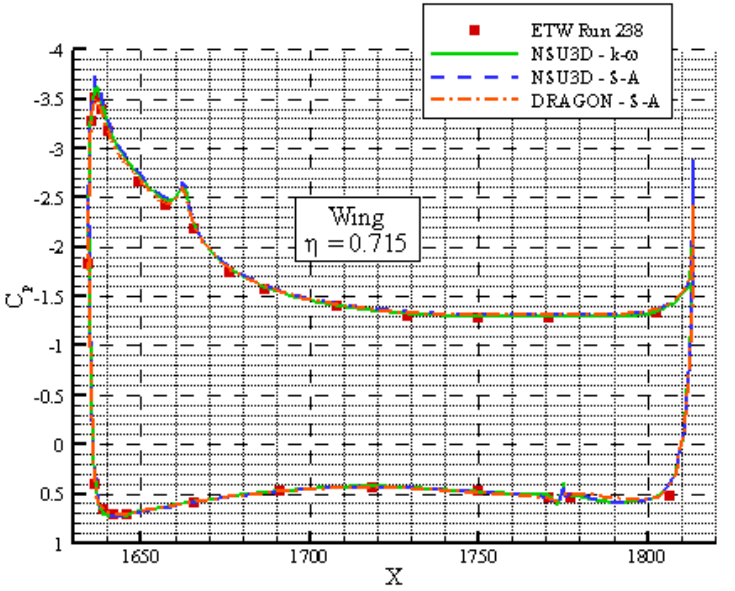


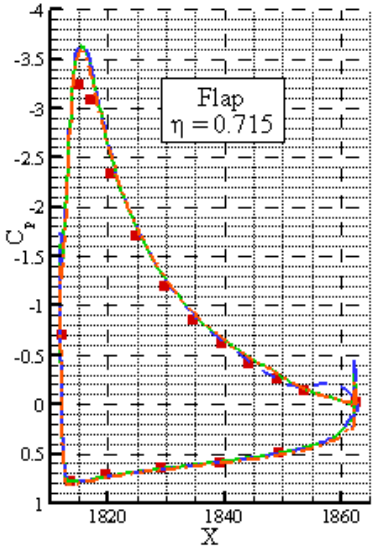




DRAGON – S-A better on slat

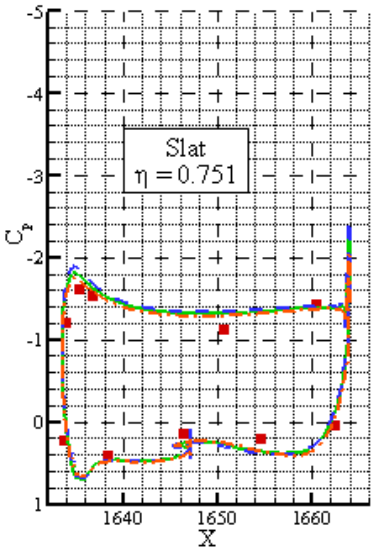


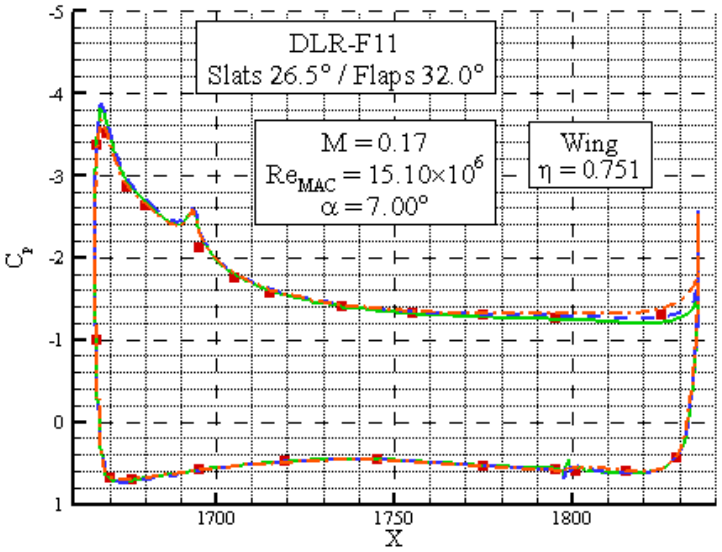


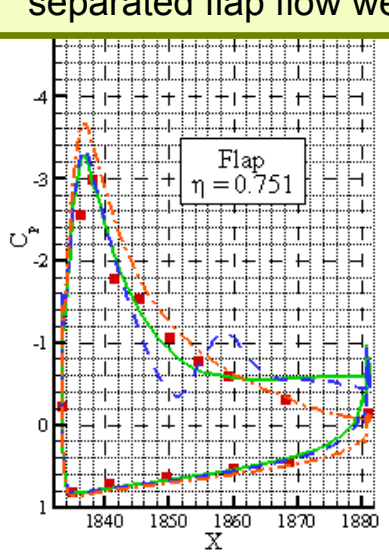


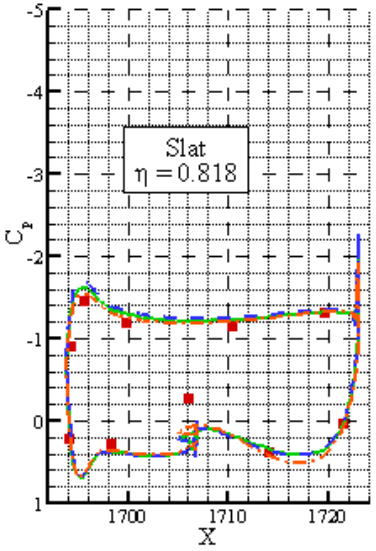
Case 2 – Solver and Turbulence Model
Surface Pressure Distributions

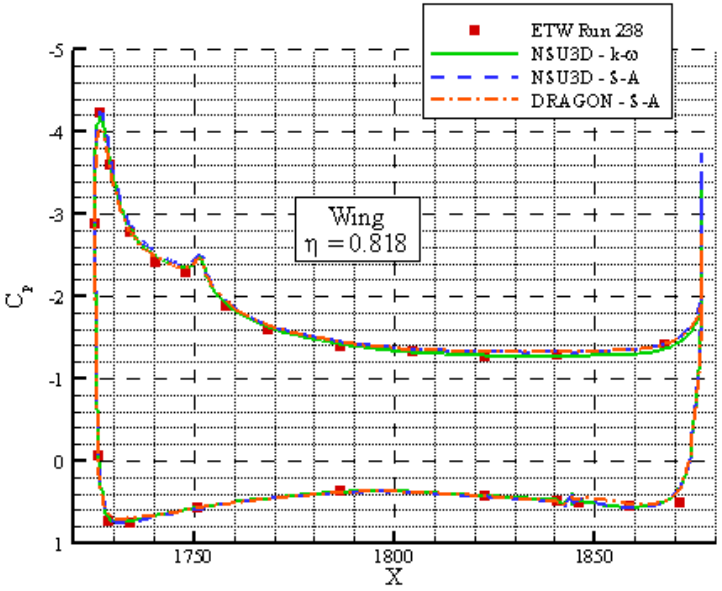
NSU3D – S-A does not predict separated flap flow well

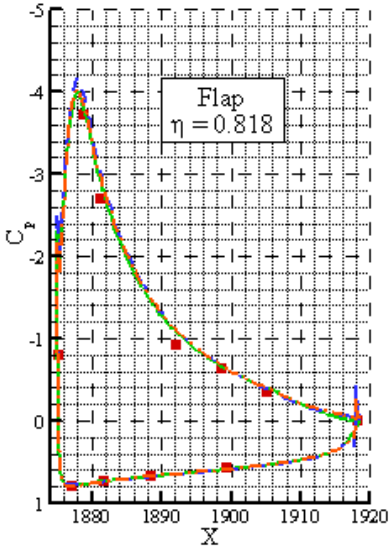








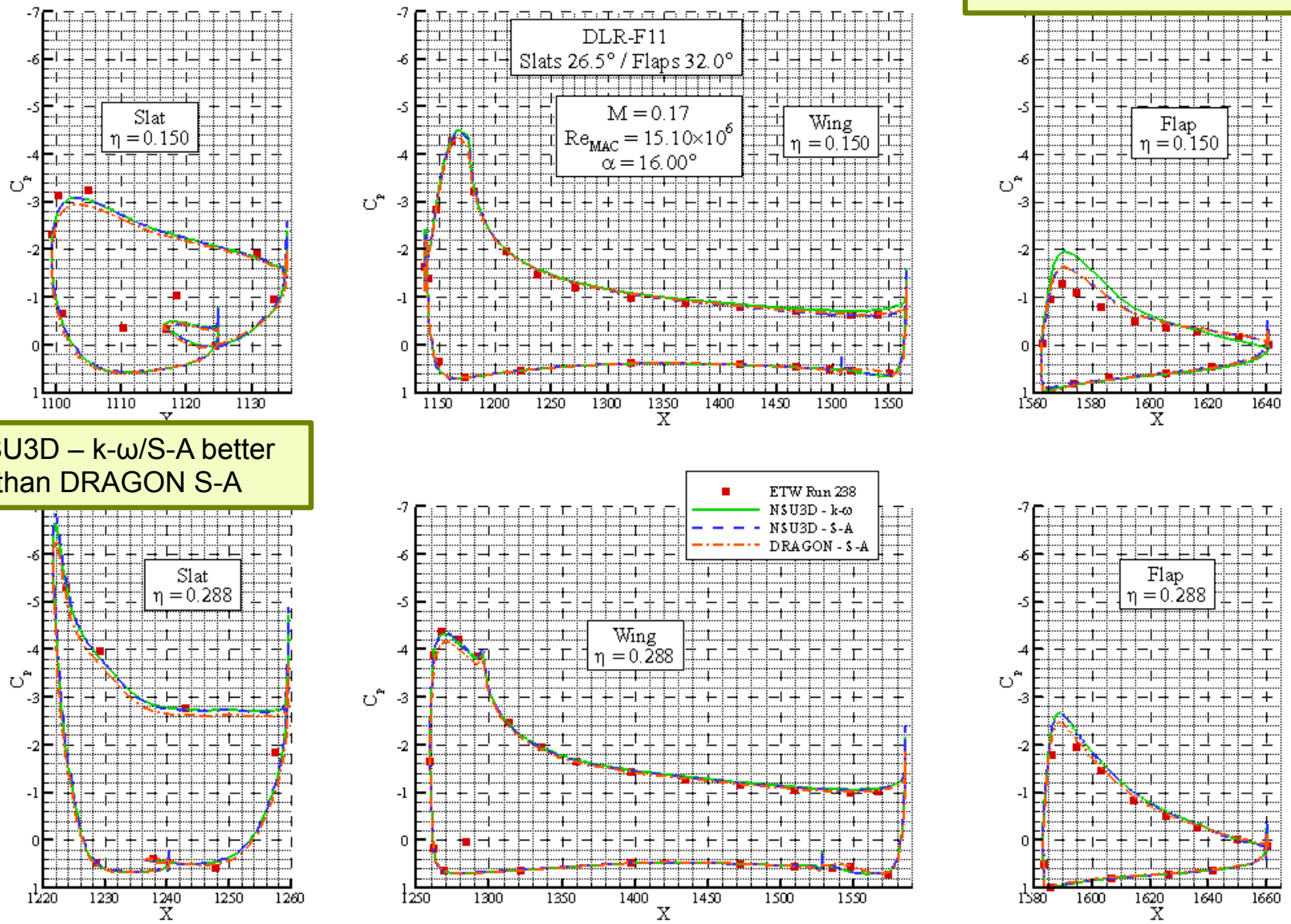




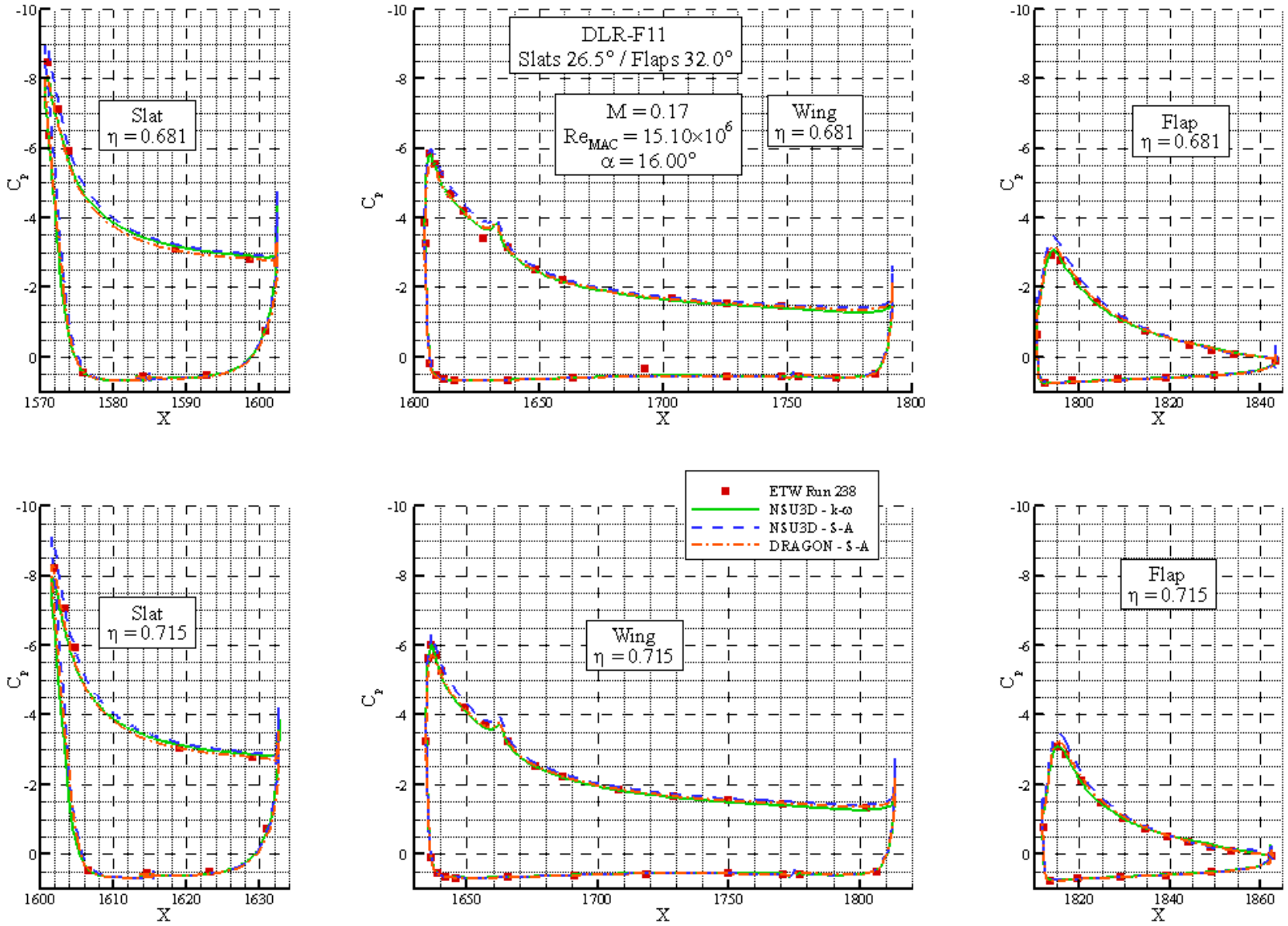
Case 2 – Solver and Turbulence Model
Surface Pressure Distributions

DRAGON/NSU3D – S-A better than NSU3D – k-ω

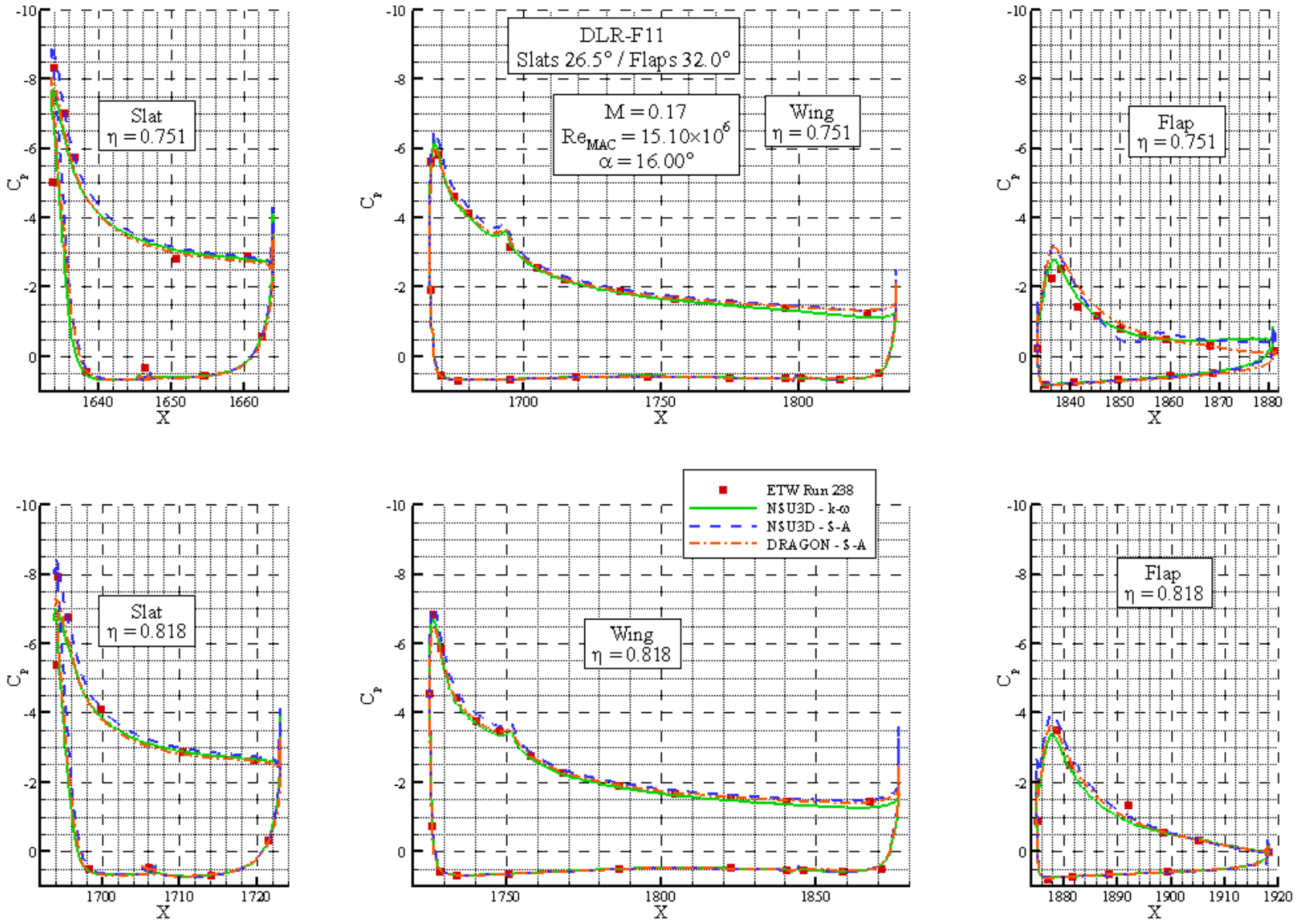
NSU3D – k-ω/S-A better than DRAGON S-A



Case 2 – Solver and Turbulence Model
Surface Pressure Distributions



Case 2 – Solver and Turbulence Model
Surface Pressure Distributions



Conclusions

- Grid convergence not achieved on Case 1
  - Issues with fine grid
- Good prediction of lift at low incidence and pitching moment trend
- C_{Lmax} underpredicted with k-ω turbulence model, no stall predicted with Spalart-Allmaras
- Very good agreement of pressure distributions with experimental data
  - Flap separated flow remains an issue
- Many possible avenues for further investigations
  - Alternate grid generation approaches, including Workshop grids
  - Laminar-turbulent transition effect
  - Turbulence modelling:
    - implement k-ω in DRAGON
    - SST k-ω in NSU3D
  - Unsteady flow computations

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the evolution of mobility